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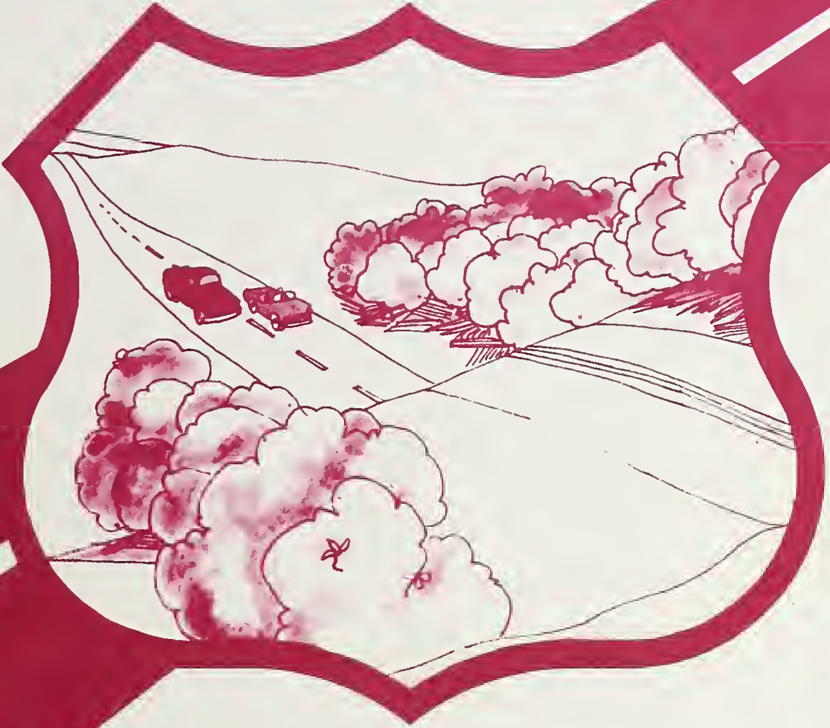
SSING AND NO-PASSING ZONES: SIGNS, ARKINGS, AND WARRANTS

September 1978
Final Report



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FOREWORD

This report describes research performed to update and provide uniform criteria and warrants for the establishment, marking, and signing of passing and no-passing zones on two-lane roadways. The significant findings are being pilot tested under a study begun in October 1978 to be completed in July 1980. The pilot test results will form the basis for further field testing before the FHWA recommends changes in the present MUTCD and AASHTO design policy.

The study was conducted by the Texas Transportation Institute (TTI) of the Texas A & M University under Contract DOT-FH-11-9164. Dr. Graeme D. Weaver was the Principal Investigator for TTI, Mr. Merton J. Rosenbaum, Jr. the FHWA Contract Manager, and Mr. Douglas H. Robertson the Project Manager for FCP Project 1A entitled "Traffic Engineering Improvements for Safety" under which the study was conducted.

Distribution includes one copy to each FHWA regional office and three copies to each division office, two of which are to be forwarded to each State highway agency.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

This report presents suggested criteria, warrants, and traffic control devices to design safe passing operations and designate no-passing zones on rural two-lane highways. The criteria are based on vehicle performance during the passing maneuver, the premise that sight distance should be provided at the critical position when the passing and passed vehicle are abreast, and evaluation of traffic control devices in providing the required visual information at this critical position. Minimum passing sight distance is defined as the sight distance necessary at the critical position to permit a passing driver to perceive an opposing vehicle at a distance sufficient to allow safe completion of the passing maneuver. An advance pavement marking system consisting of a short dotted yellow line adjacent to the roadway centerline throughout the pass completion distance is proposed, in conjunction with the no-passing zone pennant sign, to advise the passing driver that passing should not be initiated beyond the start of this marking system because there is not sufficient distance to complete the maneuver before reaching the no-passing zone. Warrants for no-passing zones are presented with lengths of advance treatment and minimum distances between successive no-passing zones for a range of expected operating speeds. An economic analysis of the expected benefits to be derived if the system were to be implemented nationwide indicates a high probability of being cost-effective (benefit cost ratio of 6.1).

Evaluation of the use of the single solid yellow centerline on rural two-lane highways to designate "restrictive" passing zones is presented based on driver understanding tests, accident rate comparison, and opinions of engineering, enforcement, and legal personnel regarding expected safety, enforcement and compliance problems.

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PREFACE

This report represents the final report of the research project entitled, "Passing and No-Passing Zones: Signs, Markings, and Warrants." Included are suggested criteria, warrants, and traffic control devices to design safe passing operations and to designate no-passing zones on rural two-lane highways. The report also contains results of the study phase to investigate the feasibility of using the single solid yellow centerline to designate restrictive passing zones where a driver might pass a slow-moving vehicle, but sight distance is insufficient to permit normal operating speed passing maneuvers.

The accident analyses and human factors laboratory studies are documented in two unpublished reports:

> "Passing and No-Passing Zones: Signs, Markings, and Warrants -- Accident Analyses" (Ref. 60), and "Passing and No-Passing Zones: Signs, Markings, and Warrants -- Human Factors Laboratory Studies" (Ref. 61).

These two documents contain tabulated data and other support data from which the suggested criteria, warrants, and traffic control devices were developed. The support documents were prepared for Federal Highway Administration use in evaluating the research results.

ACKNOWLEDGMENTS

This report was prepared by the Texas Transportation Institute (TTI) through the Texas A&M Research Foundation for the Federal Highway Administration (Contract DOT-FH-11-9164).

Accident file investigations were conducted by Anton Huber, Donald R. Hatcher, Daniel B. Fambro, and Charles Blumentritt. Human factors laboratory study development, conduct and analysis were accomplished by R. Dale Huchingson, Stephen Richards, and Conrad L. Dudek. Criteria and warrants for passing/no-passing zones were developed by Donald L. Woods. Graeme D. Weaver was the project principal investigator.

Special acknowledgment is expressed to Messrs. Charles P. Sweet and Lynn L. Seamons, California Department of Transportation and Messrs. Robert Flener and John Crossfield, Kentucky Department of Transportation, for their cooperation in assisting the research staff in the use of their photologging files and accident data. Thanks are extended to Mr. B. Barton, Texas State Department of Highways and Public Transportation for obtaining copies of the Texas accident master files for use in this study.

The research staff is particularly appreciative of the assistance given by Mr. M. B. Meyer, City Traffic Engineer, Cedar Rapids, Iowa and Mr. Richard Jolly, City Traffic Engineer, Charleston, South Carolina, during conduct of the restrictive marking human factors studies in these cities.

Special acknowledgment is extended to Mr. Merton J. Rosenbaum, Jr., FHWA Contract Manager for establishing initial contact with the many state and city agencies, for arranging the necessary workshops with federal and state engineers, legal authorities and enforcement personnel for data input and interim review of the research findings, and for his cooperation and advice throughout the research project.

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SUMMARY OF RESEARCH ACCORDING
TO STATEMENT OF WORK

INTRODUCTION

The research study, "Passing and No-Passing Zones: Signs Warrants and Markings" (Contract DOT-FH-11-9164) was conducted for the Federal Highway Administration by the Texas Transportation Institute through the Texas A & M Research Foundation. The research is documented in three reports; the Final Report, and two unpublished support documents containing tabulated data from the passing-related accident file investigation (Ref. 60), and descriptions and tabulated results of the human factors laboratory studies (Ref. 61).

Although the contract statement of work contained only two tasks, the first task included nine major subtasks and the second contained three subtasks. The order between the elements of the subtasks and the manner in which the research was conducted is not necessarily one and the same. During the conduct of the total study, there was considerable interplay between subtasks to obtain necessary data and accomplish the overall objective within time constraints, particularly with respect to conducting the human factors studies. A direct correlation to the statement of work is further complicated by the fact that as the research progressed, emphasis toward certain findings and indications was redirected with subsequent contract modifications to achieve desired results that would produce a more meaningful product. This summary, however, is written to closely follow the contract statement of work and provide a summary of the work accomplished and pertinent results for each subtask. References to the main body of this report volume, support report volumes, and appendices are included throughout to indicate where the reader may find more detail and supportive material.

RESEARCH OBJECTIVE

The objective, as stated in the contract statement of work is as follows:

> *The objective of the proposed research is to develop improved criteria and guidelines for establishing passing and no passing zones, regulatory traffic control devices and traffic regulations,*

enforcement and legal requirements that can be uniformly applied throughout the Nation for the safety and benefit of all drivers. The enforcement and legal requirements will be developed in-house by FHWA concurrently with this research contract and are not a part of this contract.

SCOPE

The scope of this work includes the development and evaluation of criteria for establishing passing and no passing zones, restrictive passing zones, traffic control devices, and warrants which can be considered for inclusion in the AASHTO policy and the MUTCD. The work will be concerned with urban and rural two-lane highways. Consideration will be given to various environmental conditions such as snow and water on the pavement and nighttime driving conditions. Research of State legislative requirements which relate to the authority of local officials to establish and enforce passing and no passing zones and restrictive passing zones will be accomplished in-house by FHWA concurrently and the results will be furnished to the contractor. [The research of State legislative requirements was accomplished cooperatively by the FHWA and the Contractor after contract modification.]

RESEARCH LIMITATIONS

Certain limitations were imposed contractually:

(1) No field data collection or observations of passing maneuvers were to be accomplished as part of this study,

(2) Accident information was to be obtained from the States of California and Kentucky both of which maintain photolog files which were to be used as aids in the study of accident data. It was required that these states be visited and that the photolog files be used. Accident data from Texas was also to be used.

(3) Human factors studies were required to evaluate candidate markings and/or sign systems (including the feasibility of symbols) that were developed.

(4) The determination of passing practices of drivers was to be determined analytically from data on practices from prior research; practices as determined from accident reports; and current vehicle design specifications and performance and their effect on sight distance, acceleration, deceleration, and stopping ability.

(5) Benefit-cost analyses were to be predicated on FHWA-supplied cost information and using benefit factors obtained from published accident and operational information.

TASK A PASSING, NO PASSING, AND RESTRICTIVE PASSING ZONE CRITERIA AND WARRANTS

Develop a factual basis for the review, validation, and/or modification of the current national and local policies, warrants, and criteria for designing and designating passing, no passing and restrictive passing zones (i.e., a zone where passing is discouraged but not prohibited) on two-lane, two-way urban and rural highways and recommend modification and/or additions to national policy, warrants, and criteria.

A summary of the accomplishments and results obtained under each of the subtasks follows with reference to the report sections where additional information may be found. References in parentheses indicating only a chapter designation pertain to the Final Report. References indicating a chapter designation with a reference number 60 or 61 pertain to the appropriate support document mentioned above and shown in the list of references in the Final Report.

Task A.1 Review of Contract FH-11-8266 Material and Other Research

Complete a review, evaluation, and consolidation of past research on passing maneuver that was begun under Contract FH-11-8266. This will include determining the value of the prior research and what portions are to be used to form the basis for the additional research under the following subtasks and for additional literature review if required.

Contract FH-11-8266, an FHWA research contract awarded previously to another contractor, had similar objectives to the study herein but involving extensive field observations and measurements of passing maneuvers. The study was not completed; however, results of the literature review and accident data were made available for this study.

Results

1. The portions of the prior research material that were useful to this study included:
    (1) Accident reports from Kentucky (ref. 60).
    (2) Identification of street locations with single solid yellow centerline in Charleston, South Carolina, and Cedar Rapids, Iowa to be used in accident analysis (Chapter 15).
2. Literature pertaining to the passing maneuver was reviewed to identify vehicle, driver and roadway characteristics, environmental factors, analytical models, criteria, legislation, and cost information pertinent to defining and evaluating passing operations and engineering criteria and warrants for passing control. Approximately 60 literature sources exhibiting application to this study are listed and annotated in the appendix of the Final Report.

Task A.2 Evaluate State Practices

Summarize and evaluate material supplied by FHWA regarding existing practices of the States and certain local jurisdictions in the design and designation of passing, no passing, and restrictive passing zones. Determine if the States' interpretation of current policy, criteria, and warrants is adequate, what variations they may apply, and if any of the variations are improvements that could be considered as recommendations to result from the subject research.

The State practices information was used to identify and evaluate unique criteria, if any, that are being employed, the type and extent of use of conventional and unique traffic control devices, enforcement policies, cost information for economic analyses and legislative policy. The FHWA-supplied material was supplemented by personal contact with a number of State agencies. State practice information is summarized and discussed in Chapter 8.

Results (*Chapter 8*)

1. All States employ short zone concept no-passing zone criteria; however, five States enforce passing operations on the long zone philosophy.
2. Four States specify minimum spacing between successive no-passing zones that are longer than the 400 ft (122 m) MUTCD specified minimum.
3. Two States permit minimum "passing" zones less than 400 ft (122 m) in mountainous areas.
4. Two States do not specify minimum passing zone length.
5. The solid yellow barrier stripe represents the primary no-passing demarcation technique.
6. Only five States use the regulatory DO NOT PASS sign (Sign R4-1) as a general statewide practice, one of which uses it only because the pavement marking is not a regulatory device. At least 17 States use the sign selectively for unique geometry, visibility during snow, and maintenance purposes.
7. One State uses the PASS WITH CAUTION sign in lieu of pavement markings in certain mountainous areas.
8. At least 34 States use the NO PASSING ZONE pennant sign (Sign W14-3) with many States adopting its use within the past two years. Sixteen States use it statewide, 18 States use it selectively.
9. The conventionally placed yellow no-passing stripe, used by most States, does not satisfy driver informational needs during the passing maneuver. (Chapter 9)

Task A.3 Analysis of Accident Data

Review accident reports and related material from highways with and without passing, no passing, and restrictive passing zones, signs and markings within a variety of geometric, environmental, and traffic conditions to determine, from the magnitude and pattern of accidents involving passing maneuvers, the apparent effectiveness of, or deficiencies in, existing signing and marking practices. Effects of change in speed limits shall be considered by reviewing accident reports from before and after the speed limit changes made during the energy crisis. Prevailing law enforcement practices shall also be considered in the review.

Approximately 13,000 accident records were studied to identify patterns of passing-related accidents and causative factors that could be attributed to geometric, environmental, and marking or signing practice. Although extensive statistical analyses were conducted on the data, the randomness of accident occurrence and lack of sufficient data in the accident records inhibited, and in many cases prohibited, formulation of conclusive identification of causative factors or driver passing practices and related problems. The accident data and methodology used to investigate the data are documented in the support document, "Passing and No-Passing Zones: Signs, Markings, and Warrants -- Accident Analyses (60).

Accident data were not available for restrictive passing zone sections of rural highways; however, accident data for urban restrictive marking streets in Charleston, South Carolina were obtained and used to compare accident rates on such streets to similar urban streets marked with the conventional dashed yellow centerline (ref. Chapter 15).

Since passing practice and problems could not be specifically identified through accident data analysis, a series of human factors studies was developed to obtain this needed information. Three specific areas of interest were addressed:

(1) driver passing practices and understanding of the legal intent of demarcation systems;

(2) problems and deficiencies associated with the passing maneuver; and

(3) the influence of various roadway and roadside factors on the decision to pass.

The human factors study results were used to evaluate performance of existing and candidate traffic control devices for passing and no-passing zones. The studies are documented in the support document, "Passing and No-Passing Zones: Signs, Markings, and Warrants -- Human Factors Laboratory Studies (61).

Results of Accident Data Investigation

1. No single variable was found to be significantly contributory to the occurrence of passing accidents on rural two-lane highways, although almost half the passing-related accidents identified occurred at intersections (Chapter 3, ref. 60).
2. Contrary to expectation, factors that would be expected to promote desirable operating conditions were found to exist in a large proportion of the accidents -- dry pavement, daytime clear conditions, tangent sections and no evidence of driver incapacitation (Chapter 3, ref. 60).
3. The data indicated a reduction in passing-related accidents in the year following the adoption of the 55 mph (88.5km/h) speed limit. The range was 15 percent (Texas) to 35 percent (California) although these reductions cannot be conclusively attributed solely to the speed limit reduction because operating speed is not recorded on the accident reports (ref. Chapter 2).
4. Workshop conferences held with law enforcement personnel from throughout the Nation indicated that they believe the passing violation to be one caused primarily by inadequate driver information systems.

Results of Human Factors Studies (ref. 61)

1. Almost all drivers encroach the no-passing zone at the end of the passing maneuver ("clip") occasionally and about 20 percent do so frequently.
2. About 40 percent of the subject drivers begin a pass over the solid yellow line ("jump") occasionally but only about 5 percent do so frequently.

3. Over 25 percent of the drivers stated that they clip to complete a pass in very short passing zones
4. About 20 percent clip because they could not see the end of the passing zone when initiating the passing maneuver.
5. Passing problems included being "cut off" by the passing vehicle as it returns to the right lane, passing with insufficient clearance to an opposing vehicle, and inability to determine passing availability around large trucks.
6. Factors influencing the decision to pass included, in rank order, the perception of an opposing vehicle, traffic control devices, and roadway geometric features. The solid yellow line was ranked above the no-passing zone pennant sign by drivers in a State using the pennant.

The above findings, in conjunction with visibility attributes of signs (ref. Chapter 9) were influential in developing candidate traffic control devices to satisfy driver informational needs for safe passing.

Task A.4 Analysis of Urban Restrictive Marking Systems

> *Specific attention shall also be given to accident reports on sections of highway where the single solid yellow centerline is being used as a restrictive passing zone. This shall include the cities of Cedar Rapids, Iowa, and Charleston, South Carolina, where this marking is, or has been used on two-lane, two-way urban streets.*

Very few rural highway locations exist where the single solid centerline marking is used. No accident data were located for the only section identified in California. During a workshop to review the research results, it was learned that a research study in Virginia (59) to evaluate the single solid yellow line as an experimental marking had been recently initiated; however, no results are available. Accident data were obtained for urban streets in Charleston, South Carolina from which accident rates were compared to similar urban streets marked with a dashed yellow centerline (ref. Chapter 15). Evaluation of the single solid yellow centerline in urban areas was supplemented by a series of human factors studies (Part 2, ref. 61) and through personal interview with traffic engineers and enforcement personnel in the two cities (ref. Chapter 15).

Results

1. The legal intent of the single solid centerline with regard to passing is diametrically opposite in the two cities. Passing is prohibited in Charleston; passing in Cedar Rapids is permitted, but discouraged. If the marking is to be used, a single meaning should be decided and "passing prohitition" is recommended as a correct meaning.
2. Based on accident rate comparison, the single solid yellow centerline exhibited no appreciable advantage over the conventionally used dashed yellow centerline. Conversely, its use did not exhibit any operational disadvantage.
3. Results of driver understanding and interpretation of the intent of the single solid yellow centerline in the urban and the rural environment are presented in Task A.7 herein, and discussed more fully in Chapter 15, and Part 2, ref. 61 and appendices E, F, and G in that document.

Task A.5 Analysis of Passing Maneuver Elements

> *Utilizing the findings of Subtasks 1, 2, 3, and 4, define current situations in which present marking practices are effective and/or deficient under a variety of geometric, environmental, and traffic considerations. Determine the characteristic elements of the passing maneuver including vehicle acceleration, deceleration, and clearance utilized by drivers of various classes of vehicles involved, in passing maneuvers. This shall include locations where signs and markings are and are not used. Included with the list of elements developed shall be the range of values for the elements.*

Visibility distances to markings and signs under various geometric conditions were used to evaluate the effectiveness and deficiencies of these devices in satisfying driver informational needs during the passing maneuver (ref. Chapter 9). Published data concerning vehicle operating characteristics were used to evaluate minimum passing distances (ref. Chapter 4). Characteristic elements of the passing maneuver were determined from operational measurements obtained in a previous passing maneuver study conducted by the Texas Transportation Institute. These distance elements are discussed in cumulative distribution manner and in the form of equations to depict the applicable range of values (ref. Chapters 3, 4, and 7).

Results

1. The barrier stripe, even for moderate speeds, is insufficient to accommodate the visual needs of a passing driver on level roadways or when the stripe begins near the crest of a vertical curve (ref. Chapter 9).
2. The proposed advance dotted marking completely satisfies the visual notification needs for all speeds as does the left-mounted NO PASSING ZONE pennant if the pennant is perceived by a driver at the critical passing position (ref. Chapter 9).
3. The black-on-white DO NOT PASS sign mounted on the right side appears to be a relatively ineffective device (ref. Chapter 9).
4. A minimum passing distance of approximately 750 ft. (229 m) is needed to permit all passenger automobiles to pass a semi-trailer truck traveling at only 20 mph (32.2 km/h) (ref. Chapter 4).
5. An acceleration capability of 1.0 mphps (1.609 kmph/sec) for design purposes will accommodate approximately 95 percent of the passenger automobiles in the traffic stream (ref. Chapter 4).
6. Vehicle roof-top heights range from about 43 to 55 inches (1.09 to 1.40 m) An object height of 3.5 ft (1.07 m) (ref. Chapter 4) is proposed for safe passing operations.
7. A driver eye height of 3.5 ft (1.07 m) (ref. Chapter 4) is proposed for design and operations.

Task A.6 Develop Passing Sight Distance Model

> *Utilizing the findings of Subtask 5, develop a new model or use an existing or modified version of an existing analytical model which will predict, for varying combinations of vehicle speeds and varying geometric conditions, the minimum passing sight distances required by the identified representative vehicles for a safe passing maneuver.*

The basic AASHTO passing maneuver model was evaluated (ref. Chapter 3) with respect to measured vehicle operations. The distance elements were defined in slightly different terminology and combined in a different manner to define "safe" passing operation based on needed driver information and operating distance to complete a passing maneuver from the critical position (defined as being when the passing vehicle is abreast of the vehicle being passed). A model to define the passing maneuver for both design and marking purposes using common terminology was developed (ref. Chapter 10 and 12).

Results (ref. Chapter 12)

1. "Minimum passing sight distance" represents the minimum sight distance at which a passing driver must first be able to perceive an opposing vehicle from the critical position (passing and passed vehicle abreast) to permit completion of the pass and provide sufficient clearance distance.
2. The term, "minimum passing sight distance," as defined above, applies to both the design process and the marking operation for two-lane highways. When available sight distance is less than the minimum passing sight distance, a no-passing zone system is warranted.
3. Total passing sight distance must be provided if a driver is to be able to perceive, at the point of pass initiation, an opposing vehicle so that the maneuver need not be aborted before reaching the critical position.

Task A.7 Feasibility of Restrictive Markings

The following four questions shall be addressed and answers provided:

- *a. Is there a need for a restrictive passing zone marking?*
- *b. Can a marking be devised to discourage, but not prohibit passing?*
- *c. What is the effect of using such a marking, i.e., is it beneficial compared to the current standard marking for passing and no passing zones?*
- *d. Can drivers accurately interpret the meaning of such a marking in relation to the new use as well as other uses of the solid yellow line?*

Factual data with which to address the questions were obtained from several sources: (1) workshop conferences with traffic engineers, enforcement personnel and researchers (ref. Chapter 15); (2) accident data analysis (ref. Chapter 15); and (3) human factors studies (ref. 61).

Results

The four questions are addressed separately with respect to the capability of the single solid yellow centerline in representing an acceptable solution to the question.

Is there a need? There is a need to provide safe passing opportunity on mountainous roadways. Proponents of the restrictive marking concept stated that a "need" existed; however, the criteria on which this "need" was based were not identified. Accident rates were not believed to be unusually high where restrictive markings (or no markings) had been used according to the proponents.

1. The identification of a "need" may be produced by an on-going field study of the single solid yellow centerline being conducted on rural highways in Virginia (ref. 59).
2. Based on the heretofore defined "safe passing maneuver," allowing passing on rural highways where less than minimum passing sight distance is afforded the driver is, in effect, trading safety for convenience.
3. Based on passing accident rate analyses, there exists no need for the single solid yellow line on urban streets if the intent is to denote passing restriction. The dashed yellow centerline functions equally well and conserves materials.

Can a marking be devised? Driver understanding studies of the single solid yellow centerline indicate that it does not display adequate information to the driver regarding the specific conditions under which passing should be attempted, even with the supplementary signing studied.

1. It is strongly believed that any system used will require signing rather than (or in conjunction with) merely the pavement marking.

2. If any unique control device system is developed to permit restrictive passing operations legally, the criteria and warrants for its usage should specifically delineate the roadway conditions on which it may be used to avoid the possibility of widespread usage merely for convenience.
3. The solid yellow line connotes passing prohibition to almost all drivers; therefore, this particular marking should be reserved for this application.
4. The intent of the single solid yellow line for designating "restrictive" passing, from the traffic engineering veiwpoint, is that the solid yellow line may be crossed to pass a slow-moving vehicle when the passing driver believes the maneuver can be accomplished without conflict. The intended meaning differs from the driver's interpretation of a solid yellow line in that drivers believe that the solid yellow line denotes sections of roadway in which passing cannot be performed safely. The contradictory meanings that are not apparent to the driver, the legal ramifications that might arise, the expected driver disrespect for the solid yellow line in general, and the philosophy of allowing drivers the legal right to decide when a control device applies, indicate that the single solid yellow line for this usage does not provide an acceptable solution.

What is the effect? The concept of restrictive passing on rural highways represents an attempt to alleviate an operational condition that is a direct result of inadequate geometric design for desired operations through use of traffic control devices with the trade-off being severely reduced driver safety and possible concomitant liability allegations against the responsible agency. These considerations must be evaluated in determining the advantages or disadvantages of using the system.

1. The concept of the solid yellow line in the vicinity of the roadway centerline to denote anything other than positive passing prohibition is in opposition to expressed driver expectancy; therefore, its use for "pass sometime, not at other times" could only degrade driver

respect for a control device they consider to be important to their personal safety.

2. In view of the current emphasis on protection against tort liability, legal rulings on the use of the solid yellow line for reasons other than that to which the vast majority of drivers apparently ascribe its meaning should be sought by agencies.

Can Drivers Interpret the Meaning? The driver understanding studies (ref. Part 2, 61) are used as a basis to answer this question.

1. Drivers in the two urban areas where it is widely used did not exhibit high understanding levels regarding its legal intent in the urban area.
2. About 50 percent of subject drivers believed it to convey "no-passing" -- analogous to the standard one directional no-passing marking or the double solid yellow centerline -- when placed in the rural situation.
3. Drivers recognized that it might mean something different than other conventional centerline markings; however, the underlying connotation throughout was that it denoted "no-passing."
4. Introduction of a "sometimes/sometimes not" intent to such a positive interpretation as was demonstrated for the solid yellow line could produce serious driver confusion and create hazardous operations on rural highways if misinterpretation occurred where opposing vehicles could not avoid conflict.

Task A.8 Delay and Accident Rate Model

Utilizing the results of the appropriate foregoing subtasks, develop a new or use an existing or modified version of an existing analytical model which will predict the delays and the accident rates which would be occasioned under varying traffic and varying geometric conditions using varying lengths and combinations of passing zones, no passing zones, and restrictive passing zones.

This subtask was included in the request for proposal to investigate potential measures of effectiveness, particularly accident rate and vehicle delay, to evaluate various passing/no-passing situations in lieu of full-scale field data collection techniques. The North Carolina State University simulation program was obtained, modified slightly to become operational on available computer facilities, and was used to determine expected accident rates and delays on simulated roadways. The model was not readily amenable to input variables such as eye/object height, no-passing criteria other than the standard MUTCD minimum sight distance criteria and warrants, variable acceleration rates, and particularly the concept of restrictive passing. To use the model for these considerations would require almost total redevelopment. The recommendation was made that simulation techniques to investigate passing operations not be used in this study and additional emphasis be placed on evaluating passing/no-passing situations and associated driver problems through human factors studies and other published results of State practices.

Results

1. The NCSU simulation model, although a well developed model, does not, in its current format, readily accept data of the form necessary to evaluate delay and accident rates under the varied criteria developed in this study.
2. The delays and accident rates produced are not sensitive to minor changes in no-passing zone lengths (nor can modified no-passing zone lengths be easily input as a data variable)
3. The model is not amenable to general operational usage by practicing engineers because unique geometrics must be input in a format not generally used by the practicing highway engineer.

Task A.9 Develop Recommendations for Criteria and Warrants

> *Utilizing the findings of the appropriate foregoing subtasks, develop a recommendation for improvements of the criteria and warrants for designating passing zones, no passing zones, and restrictive passing zones.*

The following summarize the research results and proposals for designation of passing and no-passing zones for safe passing operations. The use of restrictive passing zones on rural highways is not advocated; hence criteria are not presented.

Results

1. The design of passing zones and marking of no-passing zones should be predicated on similar criteria and employ common definitive terminology for the maneuver operational and sight distance elements (Ref. Chapter 12) Figure S-1 summarizes the proposed terminology and application.
2. At the critical position, minimum passing sight distance should be available to a passing driver to permit safe completion of the passing maneuver. Therefore, this point on the roadway represents the location to which a no-passing zone demarcation system should be referenced, although the no-passing zone does not begin until a distance downstream equal to the pass completion distance for a selected 85th percentile operating speed. A no-passing zone system is warranted when less than minimum sight distance is available.
3. For design and marking purposes, an eye and object height of 3.5 ft (1.07 m) should be used as a representative height for modern vehicles (Ref. Chapter 4).
4. An advance marking treatment consisting of a dotted yellow line adjacent to the dashed centerline preceding the beginning of the solid yellow no-passing line is proposed (preferably in conjunction with the left-mounted NO-PASSING ZONE pennant at the solid yellow line beginning point) to satisfy the passing driver's visual needs in identifying the transition from a "passing" zone to a no-passing zone (Ref. Chapter 12).
5. Figure S-2 presents proposed minimum passing sight distances, total passing sight distances, and passing opportunity distances for various operating speeds. Table S-1 presents passing sight distances and advance treatment lengths (Ref. Chapter 10).
6. Figures S-3 and S-4 present the proposed method of locating and determining the limits of no-passing zones and advance marking at vertical and horizontal curves respectively.

Establishment of No-Passing Zones

The example presented herein illustrates the application of advance treatment and no passing zones using the minimum passing sight distance warrants presented in Table S-1. The 50-mph (80.5 km/h) speed condition is

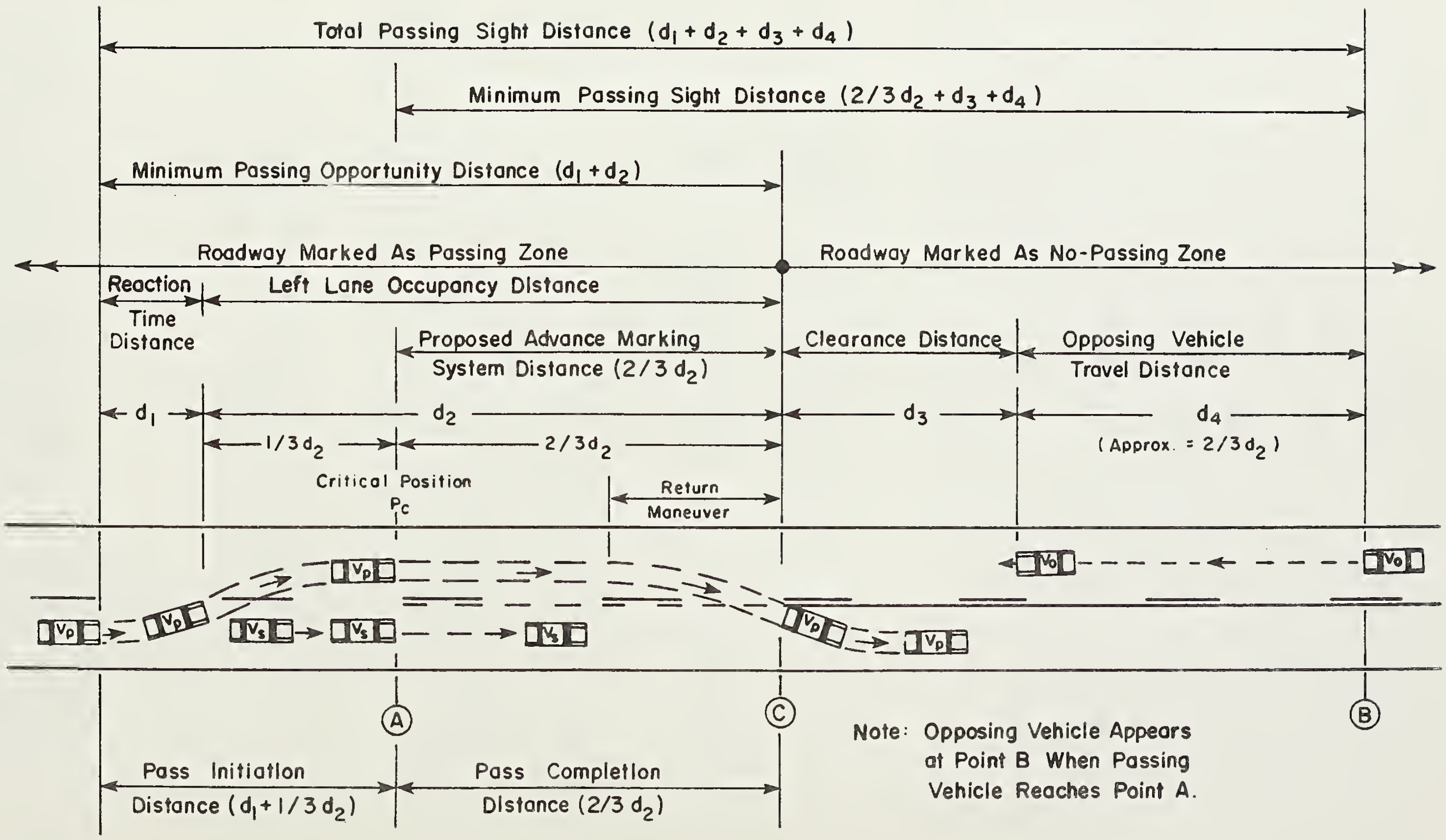

Total Passing Sight Distance ($d_1 + d_2 + d_3 + d_4$)
Minimum Passing Sight Distance ($2/3\,d_2 + d_3 + d_4$)
Minimum Passing Opportunity Distance ($d_1 + d_2$)
Roadway Marked As Passing Zone
Roadway Marked As No-Passing Zone
Reaction Time Distance
Left Lane Occupancy Distance
Proposed Advance Marking System Distance ($2/3\,d_2$)
Clearance Distance
Opposing Vehicle Travel Distance
d_1
d_2
d_3
d_4
(Approx. = $2/3\,d_2$)
$1/3\,d_2$
$2/3\,d_2$
Critical Position P_c
Return Maneuver
V_p
V_s
V_o
A
C
B
Note: Opposing Vehicle Appears at Point B When Passing Vehicle Reaches Point A.
Pass Initiation Distance ($d_1 + 1/3\,d_2$)
Pass Completion Distance ($2/3\,d_2$)

FIGURE S-1 PROPOSED DISTANCE ELEMENTS AND TERMINOLOGY DEFINING PASSING AND NO-PASSING ZONES ON TWO-LANE HIGHWAYS

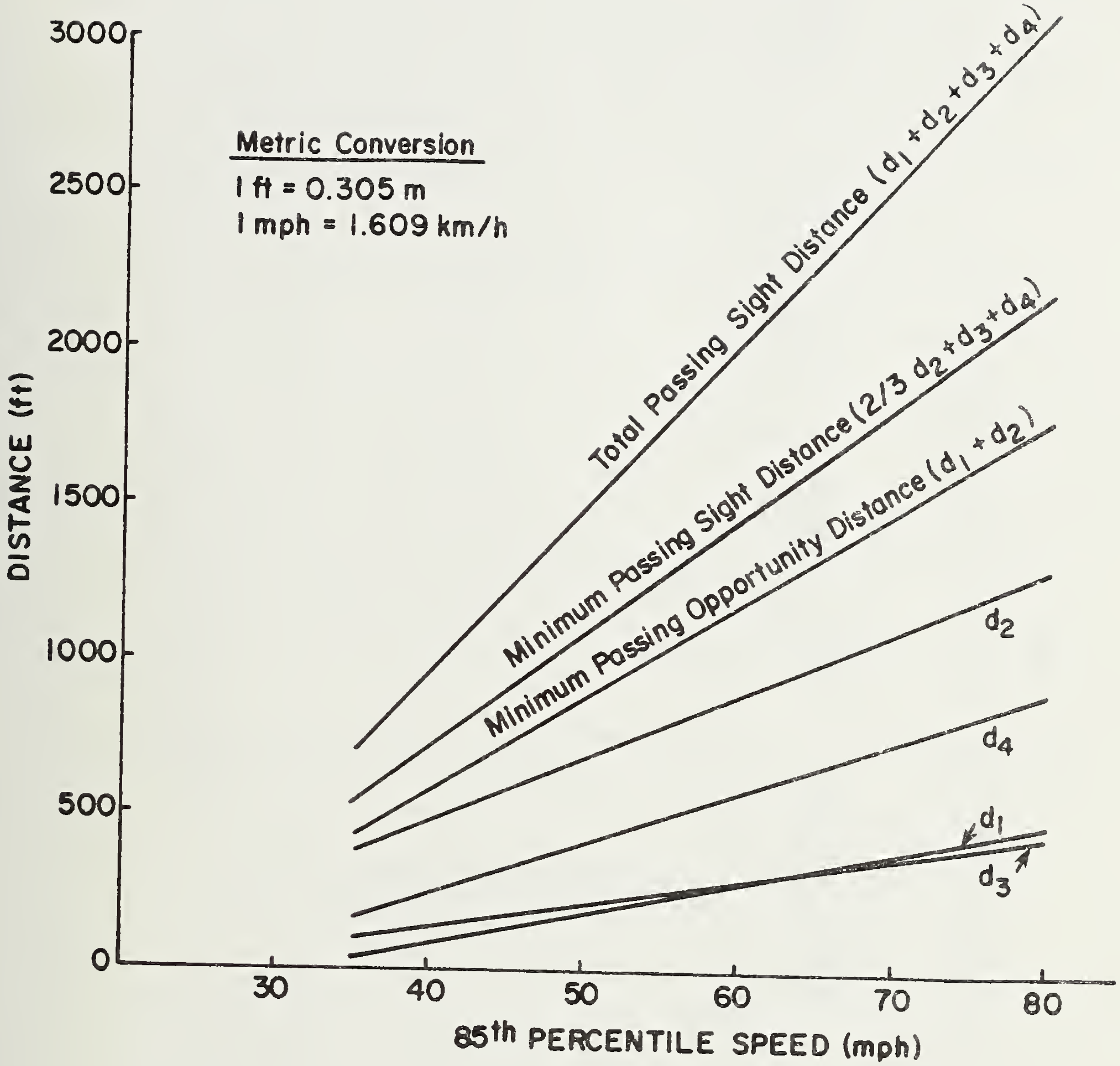


FIGURE S-2 PROPOSED PASSING SIGHT DISTANCE FOR DESIGN AND OPERATIONS OF TWO-LANE HIGHWAYS

TABLE S-1

PROPOSED WARRANTS FOR PASSING AND NO-PASSING ZONES

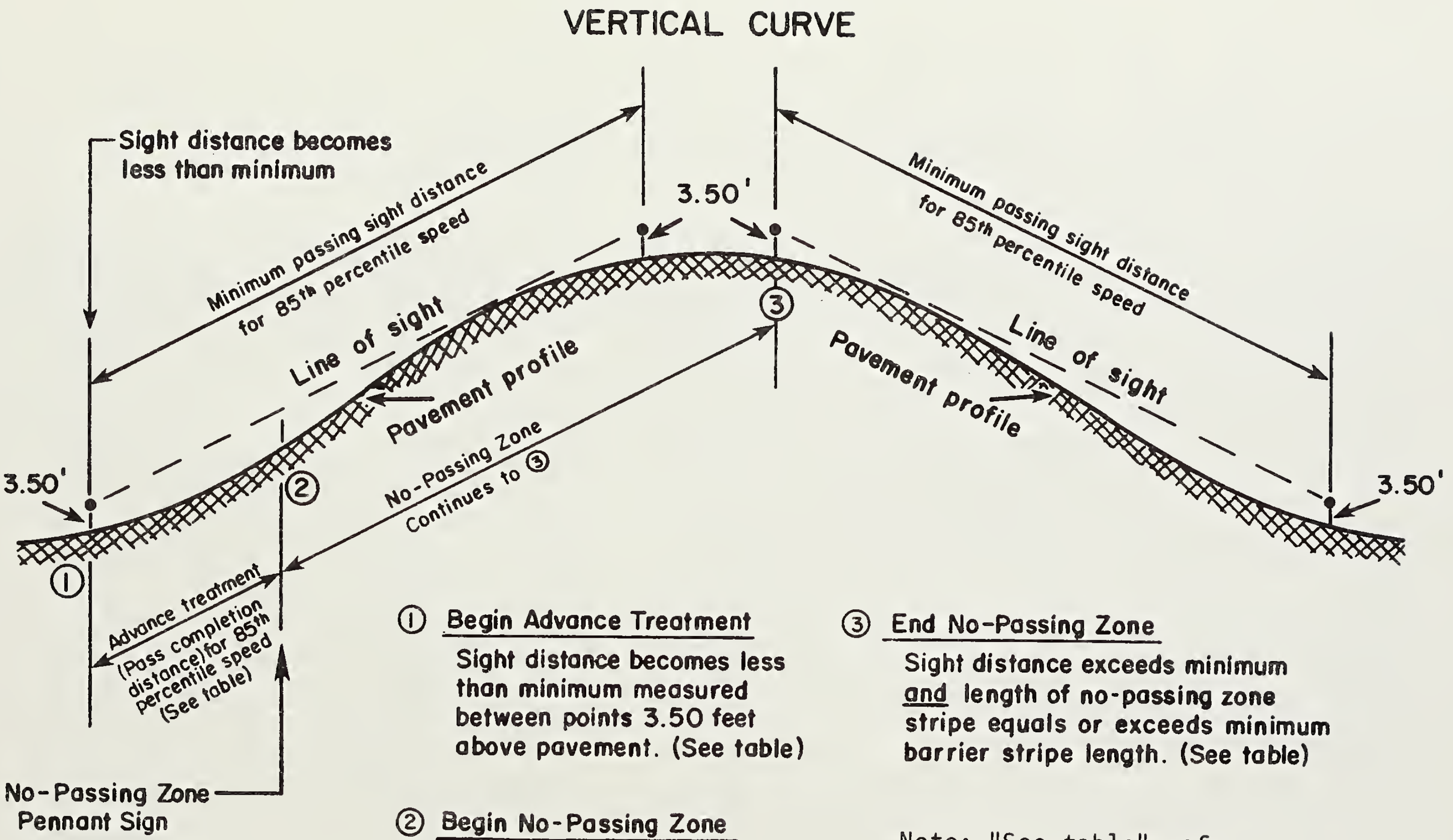
(Column 1) 85th Percentile Speed (mph)	(Column 2) Minimum Passing Sight Distance (ft)	(Column 3) Advance Marking System Length (ft)	(Column 4) Minimum Barrier Stripe Length (ft)	(Column 5) Minimum Passing Opportunity Distance (ft)
30	350	200	90	300
35	550	275	105	400
40	700	350	120	600
45	900	425	135	700
50	1100	500	150	900
55	1275	550	165	1050
60	1450	600	180	1200
65	1650	675	195	1300
70	1850	750	210	1500

Metric Conversion

1 ft = 0.305 m
1 mph = 1.609 km/h

Note: See example, "Establishment of No-Passing Zones," Item 4(b) in text and Note 3 in Figure S-4 for explanation of Minimum Barrier Stripe Length (Column 4 values) used for illustrative purposes in conjunction with Figures S-3 and S-4

1. Using a 3.5-ft (1.07 m) eye and object height and any of several accepted practices to determine sight distance along the roadway between two objects of this height, the beginning point of the no-passing zone system (Point 1, Figure S-3 or S-4) is established when the sight distance first becomes less than the minimum passing sight distance (Column 2, Table S-1) for the selected 85th percentile speed (Column 1, Table S-1). For the 50-mph example (80.5 km/h), Point 1 is established when the sight distance becomes less than 1,100 ft (335.3 m) as shown in Column 2, Table S-1.
2. The advance dotted treatment begins at Point 1 and continues for a distance of 500 ft (152.4 m) (Column 3, Table S-1). This distance represents the pass completion distance for 50 mph (80.5 km/h) operations rounded for design and marking purposes. The downstream end of the advance treatment establishes the beginning point of the solid yellow no-passing zone barrier stripe.
3. The NO-PASSING ZONE pennant sign would be placed on the left side of the roadway adjacent to the upstream end of the no-passing zone solid yellow line (Point 2).
4. The solid yellow no-passing barrier stripe would continue (Point 3) until:
    (a) the sight distance first became greater than the minimum passing sight distance of 1,100 ft (335.3 m) (Column 2, Table S-1), but
    (b) in no case would the solid yellow no-passing barrier stripe be less than the suggested minimum barrier stripe length (Column 4, Table S-1) of 150 ft (45.7 m). Adherence to this would assure that a solid yellow no-passing barrier stripe would always be placed downstream from the advance treatment even in those rare geometric situations where the minimum passing sight distance became available rapidly again after beginning the advance treatment. The minimum length of solid yellow no-passing zone barrier stripe is predicated on a two-second driver travel time for the appropriate speed.


VERTICAL CURVE
Sight distance becomes less than minimum
Minimum passing sight distance for 85th percentile speed
Minimum passing sight distance for 85th percentile speed
3.50'
3.50'
3.50'
Line of sight
Line of sight
Pavement profile
Pavement profile
No-Passing Zone Continues to ③
Advance treatment (Pass completion distance) for 85th percentile speed (See table)
①
②
③
No-Passing Zone Pennant Sign

① **Begin Advance Treatment**

Sight distance becomes less than minimum measured between points 3.50 feet above pavement. (See table)

② **Begin No-Passing Zone**

At downstream end of advance treatment (See table) No-Passing Zone pennant sign on left.

③ **End No-Passing Zone**

Sight distance exceeds minimum and length of no-passing zone stripe equals or exceeds minimum barrier stripe length. (See table)

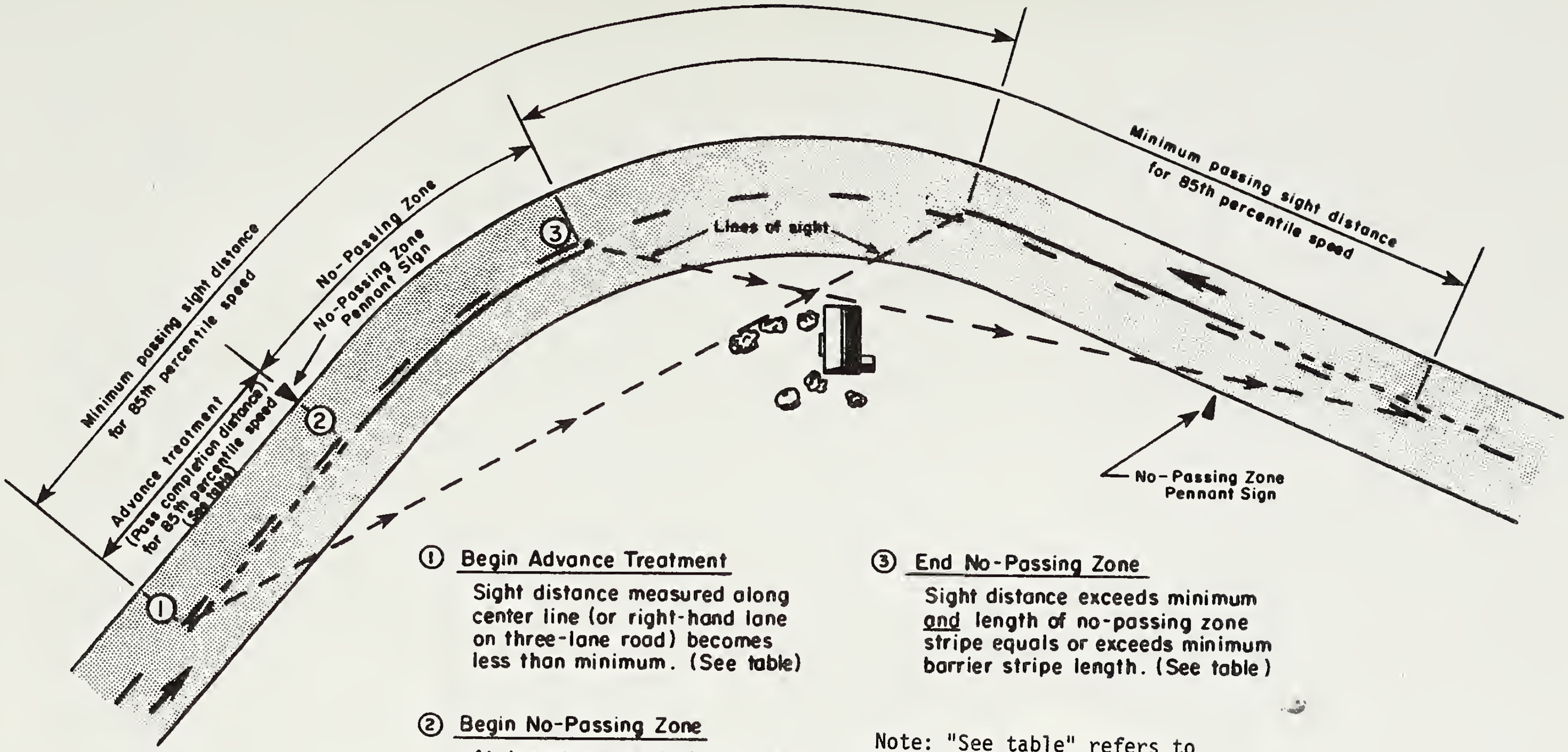
Note: "See table" refers to Table S-1

Note: No-passing zone shown for direction of travel ① to ③ only. No-passing zones in opposite directions may or may not overlap, depending on alignment.

Metric Conversion:
1 ft = 0.305 m

FIGURE S-3 PROPOSED METHOD OF LOCATING AND DETERMINING THE LIMITS OF NO-PASSING ZONES AND ADVANCE MARKING AT VERTICAL CURVES

HORIZONTAL CURVE


Minimum passing sight distance for 85th percentile speed
Advance treatment (Pass completion distance for 85th percentile speed (See table)
No-Passing Zone
No-Passing Zone Pennant Sign
Lines of sight
Minimum passing sight distance for 85th percentile speed
No-Passing Zone Pennant Sign
①
②
③

① **Begin Advance Treatment**

Sight distance measured along center line (or right-hand lane on three-lane road) becomes less than minimum. (See table)

② **Begin No-Passing Zone**

At downstream end of advanced treatment. (See table)

③ **End No-Passing Zone**

Sight distance exceeds minimum *and* length of no-passing zone stripe equals or exceeds minimum barrier stripe length. (See table)

Note: "See table" refers to Table S-1

Note: No-passing zone shown for direction of travel ① to ③ only. No-passing zones in opposite directions may or may not overlap, depending on alignment.

FIGURE S-4 PROPOSED METHOD OF LOCATING AND DETERMINING THE LIMITS OF NO-PASSING ZONES AND ADVANCE MARKING AT HORIZONTAL CURVES

TASK B REGULATORY AND WARNING TRAFFIC CONTROL DEVICES

> *From the criteria and warrants developed in Task A, develop comprehensive recommendations and guidelines for an improved, modern system of passing zone, no passing zone, and if found to be needed and justified, restrictive passing zone traffic control devices applicable for inclusion in the MUTCD based on the following subtasks.*

Although included under a separate task, most of the following subtasks were accomplished concurrently with the Task A subtasks in developing the criteria and warrants presented in Task A.9 above. The results of the Task B subtasks are summarized here to maintain continuity with the statement of work format.

Task B.1 Evaluate Need for Signs

> *Consolidate, organize, and evaluate data from previous studies and investigations of controls to determine the justification and need for signs to supplement or replace passing and no passing zone pavement markings.*

Results

The results presented are based primarily on the results of the driver informational needs evaluation (ref. Chapters 5 and 6) and the results of the human factors studies (ref. Part 1, 61).

1. The conventional solid yellow line does not satisfy needed driver informational requirements; the left-mounted NO PASSING ZONE pennant sign will satisfy the visual needs in most environmental conditions if it is perceived by the driver from the critical position (where the information is needed)
2. The DO NOT PASS sign is considered to be inferior to the more visible pennant.
3. The solid yellow line to denote no-passing is extremely well understood, conveys longitudinal limits of the applicable zone well, and should be used as the core of any system of traffic control devices to designate "no-passing."

4. Signs and/or advance dotted markings are needed to provide the required advance notification to a passing driver that the "passing zone" will soon terminate.

Task B.2 Evaluation of Candidate Sign Systems

Analyze the standard sign designs and the various sign options to determine desirable improvements or refinements including the feasibility of symbols instead of word messages. Provide for human factors studies that may be required.

Standard and innovative (including symbolic) regulatory and warning signs were evaluated in the human factors studies. (ref. 61).

Results

1. Of the approved signs available for use at no-passing zones, the NO PASSING ZONE pennant exhibits the most desirable characteristics to provide advance notification of no-passing zones. (ref. Chapter 9)
2. Symbolic signs (excluding the pennant which can be considered a symbolic or coded sign due to its unique shape and placement) to convey the dynamic passing situation are difficult to design such that high levels of driver understanding can be achieved because movement of one vehicle with respect to another moving vehicle cannot be portrayed on a planar surface. Only one symbolic sign exhibited understanding levels to warrant feasibility: a diamond shaped sign depicting a schematic dashed centerline with a solid line adjacent on the right side. The warning sign meant, "No-Passing Zone Ahead."

Task B.3 Evaluate Costs of Candidate Systems

Investigate the cost of maintaining signs and/or markings in acceptable condition the year-round especially in States with considerable mountainous or rolling terrain and with seasonable snow. The FHWA will obtain and furnish cost data from one State in each of the nine FHWA regions for the contractor's use in performing this subtask.

Task B.4 Determine the Safety Benefits From Deploying an Advanced No-Passing Marking System

In accomplishing this subtask, use may be made of a methodology developed by the Government and furnished to the contractor.

Subtasks B.3 and B.4 were accomplished simultaneously and are summarized below:

Results

1. The summarized cost information regarding signing and marking practices may be found in Chapter 11, Table 17.
2. The expected annual marking cost for installing and maintaining the advance dotted marking treatment is $7.69 per no-passing zone based on 55 mph operations (88.5 km/h). (ref. Chapter 11)
3. The expected annual signing cost to install the NO PASSING ZONE PENNANT is $10.46 per no-passing zone ($51.00/sign, 7-year sign life). (ref. Chapter 11)
4. Based on a conservative estimate of the benefits of the advance marking treatment with respect to expected passing-related accident reduction, the annual dollar saving per zone can be expected to be between 70 dollars per zone (low estimate) and 210 dollars per zone (high estimate) with a "most probable" estimate of 110 dollars per zone (ref. Chapter 11).
5. The expected benefit/cost ratio for the proposed system is:

Low estimate:	3.2
High estimate:	19.6
Most probable estimate:	6.1

6. The proposed advance treatment system has a high probability of being cost-effective if used nationwide; the findings indicate that use of the system in areas of high passing-accident frequency is warranted and a thorough field trial of the concept to measure the benefits directly is justified.

PART I PASSING AND NO-PASSING ZONES

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

With the possible exception of merging at a freeway entrance ramp, performing a passing maneuver on a two-lane rural highway is one of the most difficult and potentially hazardous tasks a driver undertakes. Despite the development of the Interstate Highway System and other divided highways, two-lane highways comprise by far the majority of roadway mileage in the United States; and almost all drivers at some time are placed in the situation of desiring to pass a slower moving vehicle ahead of them on this type of roadway. Conventional engineering practice has involved advising the driver, through use of various types of traffic control devices, of those locations along the two-lane highway where it is considered to be unsafe (and hence, illegal) to drive on the left side of the roadway to pass another vehicle. This basic practice appears to represent a rational approach consistent with the accepted philosophy of traffic control as a technique to provide safety benefits to drivers.

PROBLEM STATEMENT

The successful execution of a passing maneuver depends on a complex interrelationship among the three basic elements of the dynamic system involved -- the driver, the vehicle, and the environment in which the passing maneuver occurs. The total interrelationship may never be quantified; however a systematic dissection of each into sub-elements to identify critical driver physical and behavioral characteristics, vehicle performance characteristics, and influencing roadway features appears to represent a rational approach to identifying the problems and limitations associated with each. Thereafter, it becomes necessary to develop criteria and warrants for installation of effective traffic control devices to provide a driver the necessary informational needs to allow him (her) to adequately make judgmental decisions and subsequently execute the maneuver within the scope of personal capabilities and vehicle capabilities in the existing environment.

The ultimate goal of designating passing and no-passing zones, as in applying any type of traffic control system, is to provide a system that

(1) drivers readily understand, (2) drivers accept and believe to be necessary to their safe vehicle operation, (3) provides the necessary information to elicit the intended driver response in sufficient time, and (4) is uniformly applied. Primary emphasis must be directed toward designing any type of traffic control to meet the driver's needs. The engineering criteria on which the technical aspects of the system are based, although important to the highway agencies with whom responsibility lies in implementing and enforcing the control, are of minor concern to a driver, often times virtually even unknown. From a practical standpoint, drivers understand -- or think they understand, both being essentially the same -- the intended meaning of signs, pavement markings, and other traffic control devices. They "learn" the meaning through initial driver education in obtaining a driver's license, through continued exposure with driving experience and deduction, or sometimes through citation for traffic legal violation. Often, traffic engineers have erroneously assumed that drivers, in general, clearly understand the intended meaning of the majority of control devices present on the highway. Gordon (1) found this to be far from true; however, his study indicated that the solid yellow pavement marking on the right side of the centerline marking was the most correctly understood pavement marking used. Despite this inherent understanding, many problems exist with the current method of designating no-passing zones. Some problems can be attributed to the wide variety of State practices in demarking no-passing zones -- some States employ only the conventional solid yellow pavement marking; others use right-side mounted "DO NOT PASS" regulatory signs to designate the beginning of the no-passing zone. Still others use the "NO PASSING ZONE" pennant sign located on the left side of the roadside at the beginning of the no-passing zone. Several States use combinations of the above; some employing relatively consistent application at all no-passing zones including intersections designated as no-passing zones, others using sporadic treatment based on a determined need for an increased driver information source. The driver, thus, is presented a variety of demarcation systems in traveling throughout the country, each of which is "designed" to provide him adequate information and guidance to perform the same maneuver.

To further complicate the problem, the criteria on which no-passing zones have been established differ appreciably in concept and subsequent enforcement. The long zone concept, a supportive case having been well documented by Van Valkenburg (2), employing one set of sight distance criteria permits initiation of a passing maneuver anywhere prior to the solid yellow line and completion of the maneuver beyond the start of the solid yellow line. For those drivers merely clipping the solid yellow line during completion, this concept is assumed to provide a buffer zone since the beginning of the solid line is predicated on longer sight distance criteria than used in the short zone concept; however, the existence of a buffer zone is highly questionable for those drivers who execute a substantial portion of the maneuver beyond the start of the solid line. Only five States responding to an FHWA survey stated that they advocated use of the long zone concept; however, review of the State manuals indicated that they did not use long zone sight distance criteria in establishing no-passing zones -- they merely enforced passing operations on long zone concept by permitting pass completion beyond the start of the solid yellow line. Short zone sight distance criteria were apparently used to establish position of the no-passing barrier stripe.

If established on the proper criteria, each concept exhibits certain advantages and disadvantages when the passing maneuver is executed in accordance with the operating conditions on which each is based. The unfortunate aspect remains that drivers -- for whose use the demarcation system is intended -- in general do not know which system is in effect, particularly when driving in another State. Indeed, several highway agencies questioned during this study were not cognizant of the differences in marking criteria and intended operation between the two concepts nor which concept was in fact used within their State. The fact remains that a large majority of drivers believe that they should return to the right side of the two-lane roadway prior to reaching the solid yellow line to be legally correct and for safety. Roadways marked under the long zone concept are penalizing drivers of this common belief because, under this concept, drivers may legally encroach into the solid line area to complete a passing maneuver with assumed safety. The potentially hazardous practice of operating under the assumption that the roadway is marked under the long zone concept (for those drivers who are correctly aware of the differences) can produce extremely unsafe conditions when it actually is marked for the shorter sight distance criteria imposed by the short zone concept.

The passing maneuver is one of the most complex maneuvers a driver is required to perform. Successful performance necessitates correct judgment of many variables -- the speeds of the passed vehicle and an oncoming vehicle if in view, the distance required to pass, and correct estimation of available passing distance to name only a few. It has been well documented by researchers (4, 5, 6, 7, 8, 9) that drivers exhibit extremely inferior ability to correctly estimate variables such as available sight distance, closure speed between a passing vehicle and the passed or approaching vehicle, required passing distance or time and other judgment aspects of the passing manuever. To further compound the problems associated with correct assessment of the above, passing generally is performed at relatively high rates of speed; involves acceleration often under restricted roadway view due to the lead vehicle blockage, two steering reversals at each end of the lane change operations both of which are against crown; and with full knowledge that the maneuver is being executed within a lane reserved primarily for approaching vehicles. The speed factors alone degrade driver judgment capabilities . (4) In essence, the driver work load is taxed severely.

Vehicular characteristics present problems to successful execution of the passing maneuver. Vehicle physical dimensions, particularly roof height and concomitant driver eye height, influence the distance at which an approaching vehicle may be perceived; hence, no-passing zone demarcation criteria based on an eye height/object height relationship must logically consider the limitations imposed by these two variables. Vehicle performance characteristics such as acceleration capabilities, peak ("top-out") speeds, and handling ease at high speed affect driver performance and, hence, a decision to pass or await a more acceptable passing opportunity. Current demarcation criteria are based on certain measured performance characteristics (10, 11,). Recently required federal specifications (12) indicate an annually increasing passing distance for automobiles manufactured and/or sold in the United States. Other research studies (13) have indicated that current demarcation criteria are inadequate for safe passing execution at some speed levels for current vehicles and operating practice. Vehicle dimensional trends have been documented (14, 15, 16, 17) and reveal a continual negative influence on visibility aspects of vehicle perception from the assumptions made in early no-passing zone criteria.

Despite the varied and interrelated problems presented the driver, the visual information source on which a passing driver assesses the safety and determines the available passing distance (in the absence of an opposing vehicle) has, for years in a majority of States consisted of a solid yellow pavement marking. When viewed from the low visual angle on a level tangent road surface such as prior to a "dip" in the road or a "drop-off" over a crest, this information source represents a target of essentially zero object height. In many instances, poor line/pavement contrast further reduces visibility distance. The concept of "positive guidance," (18) is a concept which is gaining popularity because it advocates advance notification or "expectancy conditioning" to assist a driver in performing a desired operational response to a downstream event. Under this concept, the conventional yellow solid line does not rank well on the achievement scale. Deficiencies must be identified and adequate information sources developed.

State agencies have become increasingly aware of legal issues pertaining to application of traffic control devices, particularly those who have waived sovereign immunity under the Tort Claims Act. There appears to be a growing concern regarding not only application in conformance with accepted practice but also with regard to the criteria on which the standards are based. Within economic feasibility, State agencies responsible for traffic control and operations are placing increased emphasis on providing additional traffic control devices of the "warning" category not necessarily on the basis of individual site engineering evaluation but unilaterally because of legal interpretation of the "may, should, or shall" wording in the MUTCD. Also, legal wording in many State vehicle codes and manuals differs from the respective federal documents; therefore, a thorough evaluation is necessary to identify problem areas with respect to agency liability.

Enforcement problems exist with current demarcation practices. In effect, traffic enforcement officers are placed in the position of defending the validity of a citation for violation when a driver completes a passing maneuver beyond the beginning of a solid yellow no-passing line. The citation must be based on a "judgment call" criterion by the citing officer dependent on the encroachment distance and the assessment of the reason for the occurrence under the circumstances in effect at the time of the offense. Traffic officers have indicated that the courts often have dismissed cases of traffic citations for this offense when no accident resulted (19); thus officers are reluctant to issue citations with the expectancy of court leniency. This practice can lead to flagrant disregard or non-compliance with the no-passing zone marking.

In summary, criteria and warrants must be developed to determine passing and no-passing zones. The development should include consideration of driver informational needs for expected operating conditions during the passing maneuver and provide necessary guidance to elicit correct maneuver response uniformly throughout the country.

OBJECTIVES (Prospectus Statement)

The objective of the subject research is to develop improved criteria and guidelines for establishing passing and no-passing zones, regulatory traffic control devices and traffic regulations, enforcement and legal requirements that can be uniformly applied throughout the Nation for the safety and benefit of all drivers.

RESEARCH APPROACH

The performance of a passing maneuver is influenced by many separate but related variable factors -- driver, vehicle and environmental factors -- as stated previously in this report. Considerable research has been conducted in each of the three subject areas to identify and define specific characteristics and assess their individual importance to particular driver tasks. Each area constitutes a separate study element which in itself would involve considerably wider scope than could be attained within this research effort. Therefore, the approach adopted herein was to utilize, as fully as possible, applicable previous research findings concerning the elements of the passing maneuver. Field studies involving extensive traffic operational measurements were specifically omitted from the scope of the study.

The approach revolved around the basic concept that successful execution of a passing maneuver, like many other driver tasks, is dependent upon the driver's correct assessment of the visual cues presented prior to initiating the pass, and during the passing maneuver. Knowledge of his vehicle performance characteristics under the particular environmental conditions in existence at the passing location is a contributing factor in his decision to pass; however, it is believed that the critical factor is the driver's judgment and decision process based on assessment of cues received from a variety of information sources on and adjacent to the roadway.

Starting with this premise, it was necessary to identify those physical and behavioral driver characteristics that might be critical to a driver's ability to perceive, comprehend and respond adequately in a passing situation. What actions does a driver perform in executing the passing maneuver? In what sequence are they performed? What work load is imposed and at which point in the maneuver is a particular bit of information needed and can it be provided in a manner in which he can use it? How do drivers operate their vehicles during a passing maneuver? Do drivers, in fact, consider that the passing maneuver presents problems under the demarcation systems currently in use; if so, what problems exist? These questions required answers to define driver-related problems. The approach taken to determine these answers involved a combination of reviewing previous research literature, and conducting human factors laboratory studies in which subject drivers were asked to identify problems experienced with passing, being passed, and meeting on-coming vehicles passing other vehicles. The subjects were asked to interpret pavement markings from a legal understanding and an operational aspect. Also, information regarding sequential visual cues and informational sources was obtained from human factors laboratory studies.

Vehicle characteristics affecting passing performance were identified. Dimensional and acceleration data of almost all vehicles were obtained from published information (20) with which to evaluate the differences in operational characteristics of current vehicles between these vehicles and passing performance measurements obtained in previous studies (10, 13). This information was required to critically evaluate current design passing sight distance criteria (21) and demarcation practices (3) and to determine required visibility distances for informational sources.

Two research approaches come to mind when attempting to identify the degree to which the passing maneuver is influenced by roadway geometric factors, environmental factors such as rain, snow, ice, etc., and legal interpretation of driver violation. One approach involves detailed field evaluation of passing related accidents immediately following each accident over an extended period of time. This represents a very expensive method and would entail several year's effort by a trained accident team; however, it represents an effective method because the evaluation team can evaluate the accident scene under the environment in existence at the time of the accident, and equally important, discuss the accident with the drivers involved in many cases to obtain specific information relating to their actions prior and during the incident. This type of information can be obtained only through driver interview whereas official police accident reports rarely contain sufficient information with which to specifically identify causative factors relating to the roadway features. A second approach involves investigation of accident files over a period of years to identify trends in accident patterns from the limited roadway and traffic control device information that generally are contained in accident records. After identifying passing related accidents, selected accident sites may be evaluated from photologs or by visits to the site. There are certain obvious problems associated with this approach. Accident location generally is reported to the nearest tenth milepost which necessitates reviewing approximately a 1000 ft length (305 m) of roadway [500 ft (152 m) in each direction of the impact location] and many times specific location of the exact site is extremely difficult to define. Also, accident reports define the point of impact whereas the causative factors leading to the action often can be attributed to roadway or operational features considerably in advance or beyond the impact point. However, the approach taken in this research, as specified by contract requirements, involved detailed study of accident file data from three States (Texas, California, and Kentucky) in attempts to identify geometric and environmental factors that contribute to passing-related accidents. In addition to the accident file investigation, problem definition information was supplemented by driver interview techniques in the human factors laboratory studies and through workshop discussion with traffic officers from several States. State practices for designating no-passing zones were compared to identify potential improvements or innovative techniques that have been tried.

The AASHTO and MUTCD criteria and marking warrants were critically evaluated with respect to applicability of current vehicle performance, known passing operational practices, and provision of driver informational needs during the passing maneuver. Deficiencies or inconsistencies in criteria and demarcation practices were identified with respect to findings from the driver and vehicle study results from which various techniques were developed to provide needed information to a passing driver. Human factors laboratory studies were conducted to evaluate expected performance of various demarcation systems. The systems exhibiting feasibility were further studied to produce the more promising candidate systems of demarcation.

Summary of Research Approach

The research goals were:

1. To develop criteria and warrants for defining and designating safe passing operations on two-lane rural highways,
2. To develop roadway demarcation systems to designate safe passing operations.

Basic to achieving the above goals is defining "safe" passing operations. The passing maneuver was defined, based on measured vehicle performance in previous studies and knowledge of driver behavior and capabilities. The vehicle and roadway characteristics that influence successful completion of the maneuver with respect to the now-defined "safe" maneuver were identified using a combination of vehicular operational data, accident file investigation and human factors studies. From this, informational needs were determined. Current policy and practices were evaluated against the determined needs and deficiencies identified. Alternative methods were developed to enhance current practice to supply the safety needs.

CHAPTER 2

IS THERE A PASSING-RELATED PROBLEM?

The passing-related problem is multi-faceted -- encompassing enforcement, driver misapplication of intended action or response, and liability from the authoritative agency empowered to install, maintain and operate the highway system.

ACCIDENT STATISTICS

Many times the sole criterion for ascertaining that a problem exists is the occurrence of some statistically significant number of traffic accidents resulting in injuries or fatalities. It is conceded that the occurrence of accidents indicates the existence of a problem; however, it should not be considered the problem. Effective accident analysis can, however, under some situations, define causative factors, and should therefore, be considered as one factor in determining the existence of a problem, keeping in perspective the probability that many problems do not result in an "accident" and most accidents are the end product of a series of problems.

To identify the elements of passing accidents that can be considered "causative factors," a detailed analysis was conducted of accident data from California and Texas. Passing accidents occurring on two-lane rural roadways were extracted from the accident records for the years 1973 and 1975, the year before and the first full year after the nationwide adoption of the 55-mph (88.5 km/h) speed limit. These two years were selected to determine if accident occurrence changed appreciably with the reduced speed limit. Approximately 13,000 accident records were studied to isolate driver, vehicle, roadway, or environmental causative factors in passing-related accidents. The methodology used to investigate the accident data is discussed in detail in the support document, "Passing and No-Passing Zones: Signs, Markings, and Warrants -- Accident Analyses" (60).

The accident record files from California contained 1,517 rural passing-related accidents in 1973 and 1,292 accidents in 1975. From these two files, 44 roadway sections throughout the State exhibiting the highest accident frequency in both years were selected for further study. Copies of the accident reports filed by the California Highway Patrol (152 in 1973 and 127 in 1975) for these sections were obtained and studied for similar causal factors. The California Department of Transportation photolog files of the applicable roadways were reviewed from which horizontal alignment, vertical alignment, location of intersections, location of no-passing zones, type of roadway surface, and type and location of traffic control devices were identified. Upon the completion of this inventory process and the analysis of the information, the entire passing accident file for each year was then subjected to extensive frequency and regression analyses.

In addition to the data from California, accident reports were received from the State of Kentucky. From this relatively small data base no high-frequency locations could be identified, and since the accident data were not computerized at the time of this study, additional passing-related accidents could be identified only by manual search of the accident records, a process too time-consuming and expensive. From the accident records available, sites were selected for photolog review. The information from both photolog files and the accident reports was analyzed for causal factors, however, the relatively small data base did not produce any significant findings.

Of the three States chosen for accident investigation in this study, Texas exhibited the largest number of rural passing accidents -- 3,639 accidents of this type in 1973 and 2,382 accidents in 1975.

Texas passing-related accidents were classified into the categories listed:

1. All passing-related accidents occurring on two-lane rural highways,
2. All passing-related accidents occurring on two-lane rural roadways with roadway width less than 29 ft (8.8 m),
3. All passing-related accidents occurring on two-lane rural highways at non-intersection locations,
4. All passing-related accidents occurring on two-lane rural highways at intersection locations, and
5. All passing-related accidents involving a vehicle entering or leaving a driveway.

Extensive statistical analyses were conducted on these data to ascertain significant influences of a variety of variables as causal factors. Approximately 100 accident reports involving accidents that occurred in a marked no-passing zone on the same roadways during both 1973 and 1975 were studied. Also, six roadway sections with the highest frequency of passing-related accidents in both years, were identified. Five of these sites were visited to determine if additional information relative to possible accident cause could be identified.

Passing-Related Accidents Before and After the 55-mph (88.5 km/h) Speed Limit

Inspection of the data from the two years indicates a reduction in passing-related accidents after the adoption of the 55-mph (88.5 km/h) speed limit in both California and Texas; California exhibited a 15 percent reduction, Texas exhibited a 35 percent reduction. It should be noted that these reductions cannot be attributed solely to the speed limit reduction because the operating speed of vehicles involved in the passing accidents is not recorded on the traffic accident report. However, accident statistics in general indicated a reduction in total injury accidents nationwide immediately following the speed limit change with indications recently of gradual increase again.

Magnitude of the Passing-Related Accident Problem

On a national basis, passing-related accidents comprise only about 3 to 4 percent of the total annual traffic accident toll. From merely a total number viewpoint, these statistics may be regarded by some as relatively insignificant, however, even in gross generalities, based on the annual figure of about 50,000 fatalities and assuming that passing-related accidents can be considered to produce an unproportionately high number of injuries and fatalities, approximately 1000 to 1500 fatalities could be attributed to the passing maneuver. This gross estimate constitutes an economic loss of from 300 to 430 million dollars annually, excluding property damage using current accepted costs for a fatality.

Further, it is emphasized that the accident statistics reveal only those accidents coded as "passing-related" and generally include only those in which two or more vehicles were involved. It is extremely difficult to determine how many accidents coded as single-vehicle accidents or some other type actually were caused by improper passing maneuvers; thus "passing" accident statistics may be deceivingly low in actuality. The passing-related accident occurring on the open highway represents one of the most potentially severe types. This coupled with possible accident coding misrepresentation, warrants traffic engineering evaluation of the current system to improve traffic operation and safety.

ENFORCEMENT

Too often, development of engineering criteria and the subsequent design and warrants for traffic control devices are accomplished with little or no input or concern for enforcement of such devices by traffic police. Traffic police, in daily contact with the driving public, probably represent one of the most informed sources of driver behavior and of driver-stated reasons for this behavior. Since they represent the ultimate enforcing agency for compliance with traffic control devices, their collective input was considered desirable early in the research study to assist in defining problems with existing practices and to evaluate preliminary alternative improvements. The purpose was to identify deficiencies in current practice so that newly proposed systems would not, by oversight, incorporate factors that currently are presenting problems to enforcement personnel but rather would attempt to alleviate the problems in this area of consideration.

A two-day workshop was convened to determine police policies and problems relative to enforcement of current no-passing zone traffic control devices, and to identify the strengths and weaknesses of their application (19). Workshop attendees and traffic engineering officials in State and local agencies contacted after the workshop are considered to represent a cross-section of engineering and enforcement experience with respect to no-passing zones. Attendees included highway patrol personnel from five States; traffic engineers from three States; four engineers from the offices of Research and Traffic Operations, Federal Highway Administration; personnel from the National Highway Traffic Safety Administration; several attorneys; engineers from the Highway Users Federation; and the principal investigator of the research study. Follow up interviews were conducted with highway patrol personnel from nine States, engineers from highway departments in two States, and city traffic engineers from two cities. The States represented provided significant variation in vehicle code provisions relative to the statutory meaning of no-passing zone traffic controls. Also included were representatives from States enforcing passing operations on the "long" and "short" zone engineering criteria, and States using varied traffic control devices to designate no-passing zones (pavement markings and both right and left side mounted signs).

Pertinent statements expressed during the taped workshop are summarized below.

Significance of No-Passing Zone Enforcement

The police consider no-passing zone enforcement to be an important component of their traffic enforcement effort. Because of the potentially high hazard associated with a no-passing zone, police believe the regulation justifies a proportionally high share of manpower time assignments. They feel that a high level (hopefully 100%) of compliance with no-passing zone regulations is necessary (19).

The enforcement philosophy that the passing maneuver ranks high as a potentially hazardous operation is in agreement with traffic engineering philosophy. Improvements in devices that would elicit desired driver behavior during the passing maneuver are considered by the police to be helpful by reducing manpower requirements in this aspect of enforcement.

Driver Behavior

The police believe that most drivers know and respect the basic meaning (pass or do not pass) of the no-passing zone pavement marking system. Deliberate violations of the solid line "do not pass" marking are considered to be the exception rather than the rule. Instances where a driver initiates a pass in a no-passing zone, in deliberate violation of the control, are not common. This respect for the solid yellow line is evident even in States where the pavement markings alone are not an enforceable control device.

The usual no-passing zone violation is by a driver who initiated a pass in the passing area of the highway and does not complete it before the start of the no-passing zone. The workshop group referred to this violation as "clipping." Most motorists, when stopped for a clipping violation, know they were in the wrong but used the "I was trapped in the left lane" reason for their violation.

Court Action on Violations

Police officers apparently do not think there are any real problems in sustaining no-passing zone enforcement actions in court. In some States, however, when "clipping" violations are contested in court, the courts apparently often are sympathetic to the "trapped in the left lane" reason for the violation. . . In these cases, recognizing that the courts usually give considerable weight to the potential hazard of the situation that resulted in a citation being issued, the police officer's testimony is directed to identifying the potential hazards that existed at the time of the violation (19).

No-Passing Zone Designation and Enforcement Relationships

Enforcement personnel are concerned that no-passing zones are established on a reasonable basis. For example, a zone with too long an initial buffer distance, or one that was carried into the area of adequate sight distance down road, would be considered unreasonable and would create enforcement problems. Police felt that such zones would "breed contempt" for the control devices (19).

Criteria and warrants should be established on a basis that is considered to be realistic to the driver to elicit voluntary compliance. It is believed that two concepts -- "long" and "short" zone marking concepts -- produce compliance problems to drivers, particularly when they are not cognizant of the concept under which the particular highway is marked. A short zone-oriented driver in a long zone State would be expected to consider the longer upstream length of marking to be unnecessary if the driver was operating under the assumption that return to the right lane must be accomplished prior to the beginning of the solid yellow line.

Advance Visibility of No-Passing Zones

All the enforcement personnel agreed that voluntary no-passing compliance was enhanced when a driver approaching the start of a zone had a clear visual indication that the zone was ahead. This advance visibility needed to be far enough so that the driver could make an adequate judgment decision as to whether to pass or not to pass under existing conditions. The consensus was unanimous for adequate advance visibility for the system of devices establishing a no-passing zone. That is a very important control device system requirement from the police view. They feel that providing adequate advance visibility of the start of a zone is the most important improvement that can be made in the current signing and marking systems used for no-passing zones.

LIABILITY

With many States waiving sovereign immunity, the aspect of State liability with respect to installation and maintenance of traffic control devices is becoming of paramount concern. Vulnerability to suit alone may become the critical measure of the existence of problems with the current no-passing zone practices; moreover, it is submitted that future concern may be directed toward not only compliance with existing criteria and guidelines but with the validity of the criteria and warrants themselves.

Historically, State agencies have relied on the reasoning that compliance to the warrants for installation of devices absolves them of liability for the most part. The "may," "should," and "shall" terminology used in Manual on Uniform Traffic Control Devices (3) generally has been interpreted literally; however, discussion with attorneys during this research has indicated that the courts may rule no difference between "should" and "shall." Recent wording revisions (22) to the MUTCD regarding change of section 2C-29 (No-Passing Zone Sign, W14-3) from a "may be used" condition to a "should be used" condition may have been instrumental in accelerating the use of this device as an advance information source for drivers approaching a no-passing zone.

The threat of litigation vulnerability poses a decided "problem" to agencies responsible for traffic operations. From this viewpoint alone, it is submitted that current criteria, warrants, and levels of performance of methods by which no-passing zones are established require critical evaluation from the aspect of providing adequate and uniform driver guidance and control for safe passing operations. In addition, state and federal statutes regarding the placement and usage of no-passing zones deserve critical evaluation to ensure that they contain wording consistent with intent.

DRIVER MISAPPLICATION

A final problem associated with the passing maneuver is directly related to human behavior and concerns the misunderstanding and misapplication of existing passing control devices by drivers. The above discussions on passing-related accidents, enforcement of no-passing zones, and liability for inadequate passing control devices gave some indication that such a problem exists. Therefore, to gain more insight, from the driver's viewpoint, into the performance of traffic control devices at no-passing zones and identify problems experienced in the passing maneuver, a series of human factors laboratory studies was developed and administered to drivers in various parts of the country.

The most prevalent problems identified were that many existing passing zones were too short, drivers were unable to discern the beginning of a downstream no-passing zone, and drivers were unable to judge distance and time adequately. These three problem areas, all related to inadequate advance information, were stated by approximately two-thirds of the subject drivers, and were revealed as primary reasons for "clipping" a no-passing zone.

Also indicated was a misunderstanding of the legal intent of the solid yellow line. Clipping was independent of understanding; however, "jumping" to initiate a pass over the yellow line was believed to be legal if the upcoming passing zone was known to be short and no opposing vehicles were perceived.

Drivers also stated that they must take evasive action to avoid head-on collision with a vehicle passing toward them or to avoid being "cut-off" by a vehicle passing them and returning immediately in front of them. These problems can be attributed to short passing zones or failure to judge distance correctly; however, this was not substantiated specifically in the studies.

CHAPTER 3

HOW IS THE PASSING MANEUVER PHYSICALLY PERFORMED?

Before criteria and warrants can be established for determining and demarking safe passing operations, two basic elements must be defined: (1) the time/distance relationships defining the performance of the passing maneuver, and (2) the definition of a "safe" passing maneuver. Without first defining these essential basic entities would be kindred to designing a structure without knowledge of the expected loads and using an unreasonable factor of safety. Included in this chapter is a mathematical definition of the distance components comprising the passing maneuver on a two-lane highway. Also included is the definition of the distance elements considered necessary to execute a "safe" passing maneuver. A knowledge and understanding of the distance element designation presented here in and the term "critical passing distance" are considered essential to evaluating the remainder of this report.

DEFINITION OF THE PASSING MANEUVER DISTANCE ELEMENTS

In developing a descriptive "Model" of a passing maneuver two basic assumptions are made: (1) one vehicle (Vehicle P) approaches a second vehicle (Vehicle S) which is traveling more slowly than Driver P desires to travel; therefore, given an opportunity, Driver P will pass Driver S. A distance, d_1, is traveled in the time interval in which Driver P assesses the situation, decides that a passing maneuver may be safely initiated and encroaches on the left lane. Distance d_1 is dependent on several factors including one acceleration rate if Driver P was constrained to following Vehicle S for a distance such that the two vehicle speeds were equal; a different acceleration rate if Driver P was closing rapidly on Vehicle S and was not constrained to following at the slower speed; Driver P's reaction time which is a function of driver ability to assess the safety of the operation; and the speeds (both discrete and relative) of the two vehicles involved.

After moving to the left lane, Vehicle P travels a distance d_2 in which it moves to a distance ahead of Vehicle S and returns to the right lane. Distance d_2, therefore, represents the total left lane occupancy distance from point of left lane encroachment to the point where the vehicle crosses back over the roadway centerline in returning to the right lane. Distances d_1 and d_2 comprise the total distance along the roadway necessary to initiate and complete the maneuver; several studies (11, 23, 13) have been conducted in which these distances have been measured and time/distance relationships have been quantified to define vehicle position at various positions throughout the maneuver.

Note that no mention has yet been made of an opposing vehicle, necessary clearance between passing Vehicle P and opposing Vehicle O at the time Vehicle P returns to the right lane, or the distance traveled by opposing Vehicle O. These factors must be incorporated into the model to define distance elements necessary for safety but can be done only after safety is defined. Defining safety with respect to the passing maneuver can be accomplished by applying known time/distance relationships during d_1 and d_2 to computed travel distance, d_4, of the opposing vehicle for a given speed and clearance distance, d_3, that can be expected to be acceptable to drivers. An analysis of d_1 and d_2, presented here, is used to determine necessary d_3 and d_4 distance.

Analysis of Distance Elements d_1 and d_2

Two important findings by Prisk (11) and Normann (23) and verified from measurements of actual passing maneuvers by Weaver and Glennon (13) in 1971 are used here to define necessary distance elements for safety in the passing maneuver:

1. Both research studies indicated that the passing Vehicle P traveled to a point approximately abreast of the slower passed Vehicle S at the one-third point of left lane occupancy distance, d_2,
2. the speed differential at this position between passing Vehicle P and passed Vehicle S was approximately 10 mph (16.1 km/h) and that this speed differential was maintained throughout the remainder of distance d_2.

Weaver and Glennon (13) also found that the distance traveled by the opposing vehicle was very close to the 2/3 d_2 distance assumed in the AASHTO passing model. Basic to defining a "safe" passing maneuver is the determination of the point of commitment in the maneuver. This critical position occurs when the passing and passed vehicle are abreast. Not only is the passing driver "psychologically" committed to completion of the maneuver upon reaching this critical position, this decision will result in returning to the right lane ahead of the passed vehicle in less time than slowing and returning behind the vehicle to be passed. Driver P may abort the passing maneuver at any point up to this "critical" position if an opposing vehicle is perceived. From this rationale, it is deduced that, if Driver P is to be provided sufficient passing distance to avoid interference with an opposing vehicle, Vehicle O must be perceived no later than the time Vehicle P reaches the "critical" position. Quantifying the distance traveled by an opposing vehicle during the pass completion distance, 2/3 d_2, and an acceptable clearance distance, d_3, the total passing distance and necessary passing sight distance to permit safe completion can be determined.

Figure 1 illustrates the distance elements involved in execution of the passing maneuver. The elements may be quantified using computed vehicle operational characteristics, measured vehicle performance, or a combination of both. The subsequent section presents a comparison between computed critical passing distance for assumed vehicle operating conditions and distances measured by Prisk (11) and Weaver and Glennon (13).

CRITICAL PASSING DISTANCE

To enhance completion of a passing maneuver with sufficient clearance between opposing vehicles, critical passing distance is defined as the summation of clearance distance d_3 and the total distance traveled from the critical abreast position until the passing vehicle has returned to the right lane, or, 2/3 d_2. An absolutely minimum passing distance, allowing a clearance, would be 2/3 d_2. These distances are computed using the following assumptions and Figure 2 for illustration.

Assumptions:

1. Speed of passing vehicle = V
2. Speed of passed vehicle = V-10

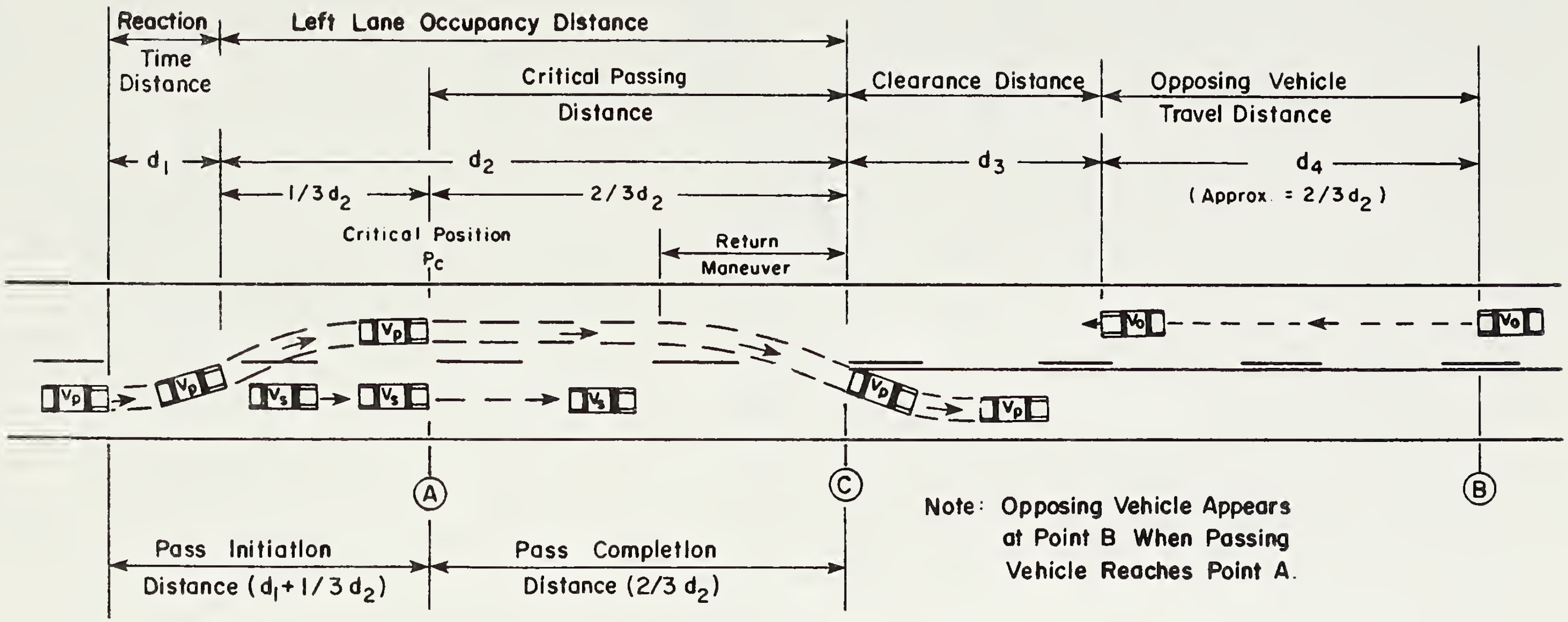
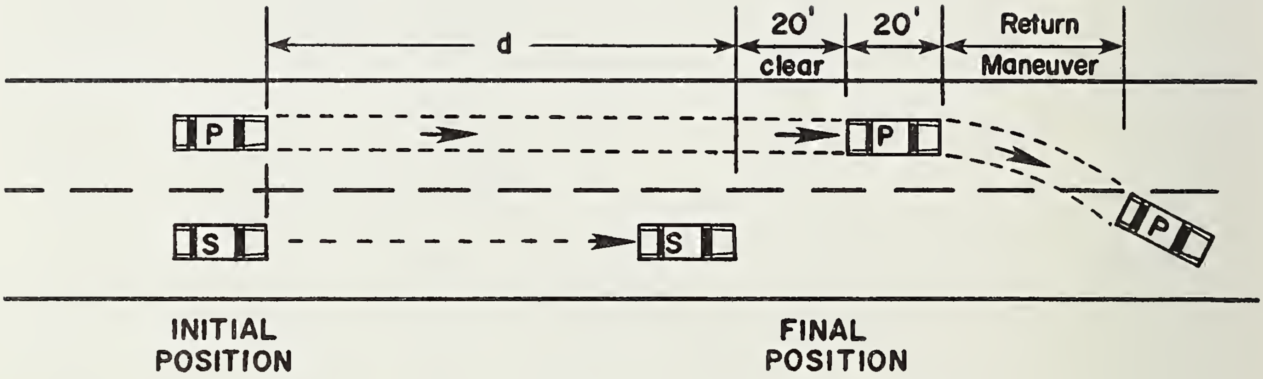


FIGURE 1 DISTANCE ELEMENTS OF THE PASSING MANEUVER



Metric Conversion

20 ft = 6.1 m

FIGURE 2 10 MPH (16.1 KM/H) ASSUMED PASSING SITUATION

3. Speed of opposing vehicle = V
4. V is 85th percentile operating speed in mph
5. Passing vehicle, P, is in the critical passing position when it is adjacent to the passed Vehicle, S.
6. Vehicle P travels beyond Vehicle S until there is a clear distance of one vehicle length, 20 ft (6.1 m) separation before the return maneuver is initiated
7. Distance traveled by Vehicle P during the return maneuver is equal to the left-lane maneuver distance, 1/3 d_2, as measured by Prisk (11).

Under the above assumptions,

1. Total distance traveled by Vehicle P before initiating return maneuver = d + 40 (Ref. Figure 2)
2. Distance traveled during this time by Vehicle S = d.
3. Equating these:

   $$\frac{d + 40}{V} = \frac{d}{V - 10}$$

   or d = 4V - 40 where d = distance in ft (1 ft = 0.305m)
4. Adding the 1/3 d_2 return maneuver distance (Prisk Values) to this value produces the absolute minimum passing distances presented in Columns 2 of Table 1 with Prisk values (11) and Weaver and Glennon values (13) shown for comparison in Columns 3 and 4, respectively. Figure 3 presents these data graphically and illustrates that the three data sources show similar trends throughout the speed range with the more recent data indicating approximately 10 percent shorter pass completion distances.

TABLE 1

PASS COMPLETION DISTANCES FROM CRITICAL POSITION

(Column 1) 85th Percentile Speed	(Column 2) 10-mph Speed Assumption Passing Distance**	(Column 3) 2/3 d_2 Observed by Prisk	(Column 4) 2/3 d_2 Observed by Weaver and Glennon
mph	ft	ft	ft
30	238	316	181*
40	333	427	325*
50	435	550	461
60	544	687	598
70	650*	NA	733

* Extrapolated values

** Values in Column 2 = 4V-40 + 1/3 Prisk d_2 value.

Metric Conversion

1 mph = 1.609 km/h

1 ft = 0.305 m

Passing Sight Distance Associated with Critical Passing Distance

Passing sight distance associated with only the "critical" passing distance would be 2/3 $d_2 + d_3 + d_4$. A driver must be able to see at least this distance along the roadway from the critical position to assure that an opposing vehicle is not so close that the maneuver cannot be completed with adequate opposing vehicle separation as Driver P returns to the right lane. Assuming that an opposing vehicle is traveling at the same speed as the passing vehicle (Prisk's assumption), the minimum sight distance to complete the passing maneuver from the "critical" position may be computed for the assumed passing model as shown in Column 2 of Table 2. Columns 3 and 4 present distance requirements for the same portion of the maneuver as found by Prisk (11) and Weaver and Glennon (13). Column 5 presents the

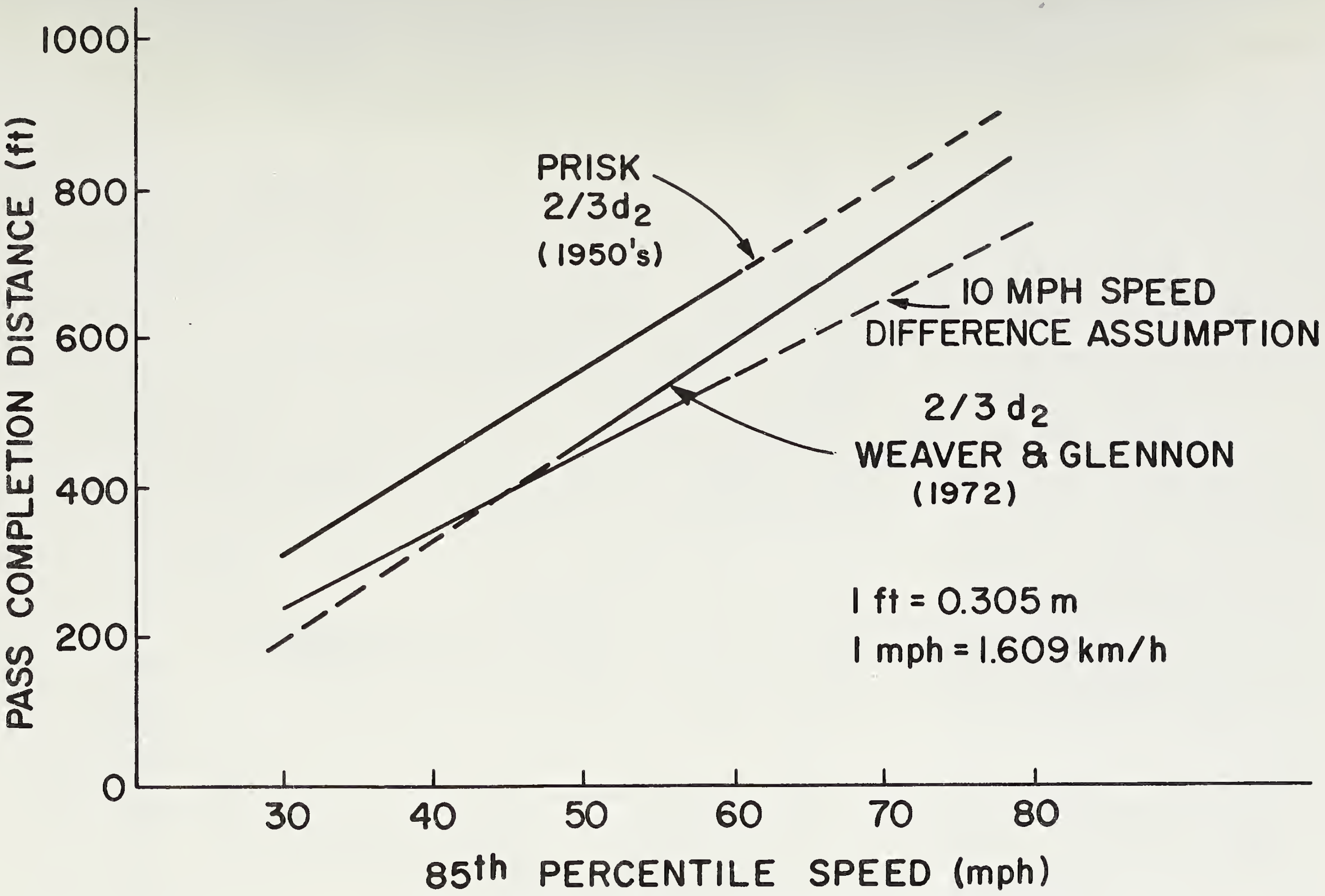


FIGURE 3 COMPARISON OF PASS COMPLETION DISTANCES (2/3 d_2)

passing sight distances specified in the MUTCD (3) for designating no-passing zones on two-lane roadways.

Figure 4 presents a comparison of the minimum passing distance values to the MUTCD specified minimum sight distance values for designating no-passing zones. The three basic data sets reveal similar trends for the higher-speed passing maneuvers and substantial variation for the lower-speed maneuvers. The MUTCD criteria, as indicated in Figure 4, are similar only in general upward trend as speed increases; however, it is apparent that the MUTCD values are substantially lower for the higher-speed passing maneuvers.

TABLE 2
MINIMUM SIGHT DISTANCE REQUIREMENTS
TO EXECUTE THE CRITICAL PORTION OF THE PASSING MANEUVER

(Column 1) 85th Percentile Speed	(Column 2) 10 mph Speed Assumption	(Column 3) Weaver & Glennon (13)	(Column 4) Prisk (11)	(Column 5) 1971 MUTCD (3)
	Col. 2 Table 1 $+d_3+d_4$**	$2/3d_2+d_3+d_4$	$2/3d_2+d_3+d_4$	
mph	ft	ft	ft	ft
30	653	333*	732	500
40	938	708*	1032	600
50	1235	1083	1350	800
60	1524	1456	1667	1000
70	1840*	1831	N.S.	1200

* - extrapolated **d_3 + d_4 represent AASHTO values

N.S. - Not stated

Metric Conversion

1 mph = 1.609 km/h

1 ft = 0.305 m

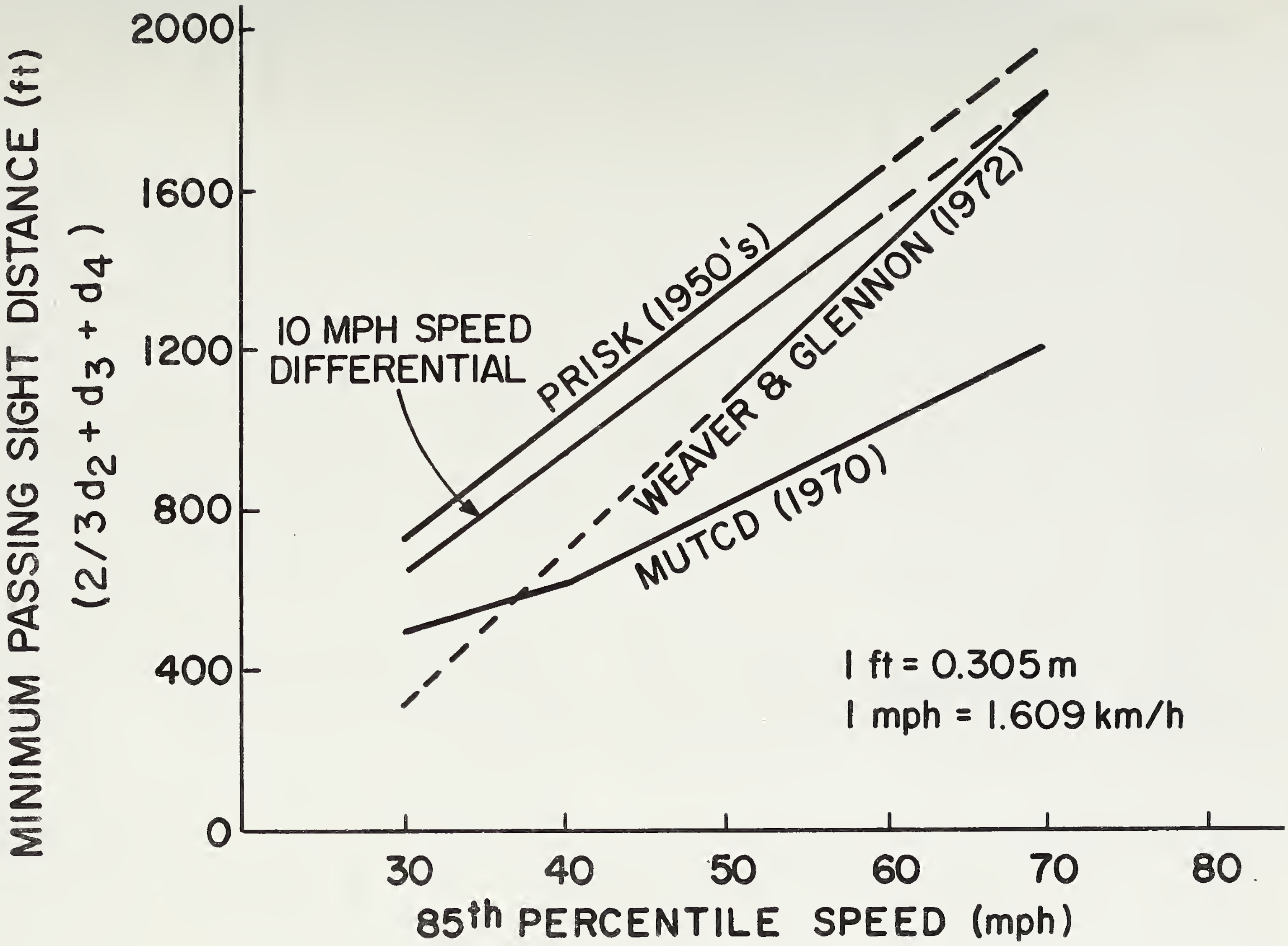


FIGURE 4 COMPARISON OF MINIMUM PASSING SIGHT DISTANCES TO MUTCD DISTANCES

CHAPTER 4

HOW DO VEHICLE AND ROADWAY CHARACTERISTICS INFLUENCE THE PASSING MANEUVER?

The vehicle is an integral component in the passing maneuver. Performance characteristics dictate minimum distances in which one vehicle can pass another; translated to engineering criteria, performance characteristics become the basic element in establishing minimum passing zone lengths if a driver is to be provided sufficient distance in which to pass without being forced to illegally encroach on the no-passing zone downstream. Vehicle physical dimensions must be considered in developing safe criteria for passing operations. The primary characteristic is vehicle height and concomitant driver eye height because these determine the distance at which opposing vehicles are perceived. Also of importance is the composition of traffic by vehicle type. Large trucks create passing problems in two ways. They generally exhibit low speeds on the rising portion of crest vertical curves and high acceleration rates on the downward portion. The former can produce a queue of vehicles that is reduced to the slower truck operating speed and the latter inhibits passing where sufficient sight distance may be provided; however, relative speeds are high. Trucks also inhibit visibility of the trailing driver due to greater height, width, and lack of through-vision capability.

An important consideration, from a driver expectancy aspect and from a legal standpoint, is uniformity in type and placement of traffic control devices. Obtaining uniformity in design of a particular device is not difficult; however, defining the placement of a device and the criteria by which it is to be placed is somewhat more intangible, particularly when the device applies to a length of roadway rather than a discrete point location. Roadway features change appreciably over several thousand feet of distance and the driver's assessment of the roadway conditions can be expected to differ throughout the section. The influence on passing exerted by the variety of roadway features present and their complex combinations must be considered during development of no-passing zone criteria and warrants if uniformity of traffic control device placement is to be achieved.

A combination of vehicle performance analysis, investigation of accident report driver and police comments, human factors laboratory studies, and previous research on vehicle dimensions was used to identify vehicle and roadway-related problems associated with the passing maneuver and to develop criteria to ameliorate the problem.

VEHICLE ACCELERATION CAPABILITIES

Most basic to the time required to execute a passing maneuver is the acceleration capability of the passing vehicle; however, primarily the d_1 phase of the maneuver is affected. Vehicle acceleration capabilities are published in Consumer Reports (24-28). Vehicle passing data information furnished by vehicle manufacturers are published annually by NHTSA (20, 29-33). These two data sets exhibit one deficiency; they reflect vehicles that are performance tuned to an optimum level rather than being generally representative of vehicles on the highway. These are, however, the most current data available, and were used to establish the basis for estimating the d_1 distance of the passing maneuver.

Tables 3 and 5 contain frequency distribution data from the two fundamental sources noted above. Table 4 presents acceleration times for a variety of vehicle types. Assuming that criteria should accommodate the 95th percentile vehicle in the traffic stream, Figure 5 indicates an acceleration of 0.8 and 0.9 mph per second throughout d_1 (1.29 and 1.45 kmph/sec, respectively).

From Table 5 the 5th percentile acceleration is between 1.0 and 1.3 mph per second (1.6 and 2.1 kmph/sec, respectively). From these data, it is recommended that the acceleration during the initial maneuver to enter the left lane (d_1) be assumed as 1.0 mph per second (1.6 kmph/sec).

MINIMUM PASSING DISTANCE

The argument for not closing up relatively short gaps between successive no-passing zones traditionally has been that provision of even short "passing" zones will permit a driver to pass a slow-moving vehicle, whereas closure with a no-passing barrier marking might result in an impatient driver passing

TABLE 3

FREQUENCY DISTRIBUTION OF PASSING TIMES FOR 1976 MODELS DURING HIGH SPEED PASSING (20)

Passing Time Group (sec)	Average Acceleration (mph/sec)	Frequency	Cumulative Frequency	Cumulative Percentage (%)
8-9	4.96	0	0	
9-10	4.01	1	1	0.2
10-11	3.31	3	4	0.8
11-12	2.79	11	15	3.1
12-13	2.37	28	43	8.8
13-14	2.04	40	83	17.0
14-15	1.78	100	183	37.6
15-16	1.57	85	268	55.0
16-17	1.39	68	336	69.0
17-18	1.23	42	378	77.6
18-19	1.11	35	413	84.8
19-20	1.00	35	448	92.0
20-21	0.91	8	456	93.6
21-22	0.83	15	471	96.7
22-23	0.75	5	476	97.7
23-24	0.70	3	479	98.4
24-25	0.64	3	482	99.0
25-26	0.59	2	484	99.3
26-27	0.55	2	486	99.8
over 30		1	487	100.0

Metric Conversion

1 mph/sec = 1.609 kmph/sec

TABLE 4

SUMMARY OF ACCELERATION CHARACTERISTICS FOR 1976-77 VEHICLE MODELS (24, 25, 26, 27, 28)

Model	Bodystyle	Acc. Time 45-65 mph (72.4-104.6 km/h) (sec)	Acc. Time 0-60 mph (0-96.5 km/h) (sec)	Acc. Time 0-30 mph (0-48.2 km/h) (sec)
Chevrolet Caprice Classic (24)	Passenger Car	8.2	12.5	5.0
Oldsmobile Cutless Supreme (24)	Passenger Car	13.0	19.0	6.2
Dodge Monaco (24)	Passenger Car	8.8	13.7	5.1
Mercury Cougar (24)	Passenger Car	9.5	14.9	5.6
Volvo 245 (25)	Passenger Car	9.7	15.7	-
Plymouth Volare Premier V-8 (25)	Passenger Car	8.6	13.2	-
Peugeot 504 (25)	Passenger Car	15.5	21.9	-
Toyota Mark II (25)	Passenger Car	10.5	15.5	-
Volkswagen Rabbit (26)	Compact Car	9.1	14.5	5.2
Pontiac Sunbird Coupe (26)	Compact Car	12.0	16.0	5.4
Toyota Corolla (26)	Compact Passenger Car	12.2	18.2	6.4
Ford Mustang II (26)	Compact Passenger Car	10.0	15.8	5.9

TABLE 4 (Continued)
SUMMARY OF ACCELERATION CHARACTERISTICS FOR 1976-77 VEHICLE MODELS

Model	Bodystyle	Acc. Time 45-65 Mph (72.4-104.6 kmph) (sec)	Acc. Time 0-60 Mph (0-96.5 kmph) (sec)	Acc. Time 0-30 Mph (0-48.2 kmph) (sec)
AMC Pacer (28)	Compact Passenger Car	9.4	15.6	5.6
Pontiac Catalina Safari (26)	Compact Passenger Car	9.7	14.3	5.6
Plymouth Voyager Sport (27)	Van	9.9	14.8	6.1
Chevorlet Beauville Sportvan (27)	Van	9.3	14.2	5.3
Ford Chateau Club Wagon (27)	Van	9.4	14.6	5.1

TABLE 5
FREQUENCY OF VEHICLE
ACCELERATION CHARACTERISTICS FOR 1976-77 VEHICLE MODELS

(Source: Table 4)

Acceleration Group (mph/second)	Frequency -	Cumulative Frequency -	Percentage of Observations Less Than High Side of Group (%)
1.0-1.2	0	0	0
1.2-1.4	1	1	5.9
1.4-1.6	1	2	11.8
1.6-1.8	2	4	23.5
1.8-2.0	2	6	35.3
2.0-2.2	8	14	82.4
2.2-2.4	2	16	94.1
2.4-2.6	1	17	100.0
2.6-2.8	0	17	100.0

Metric Conversion

1 mph/second = 1.609 kmph/second

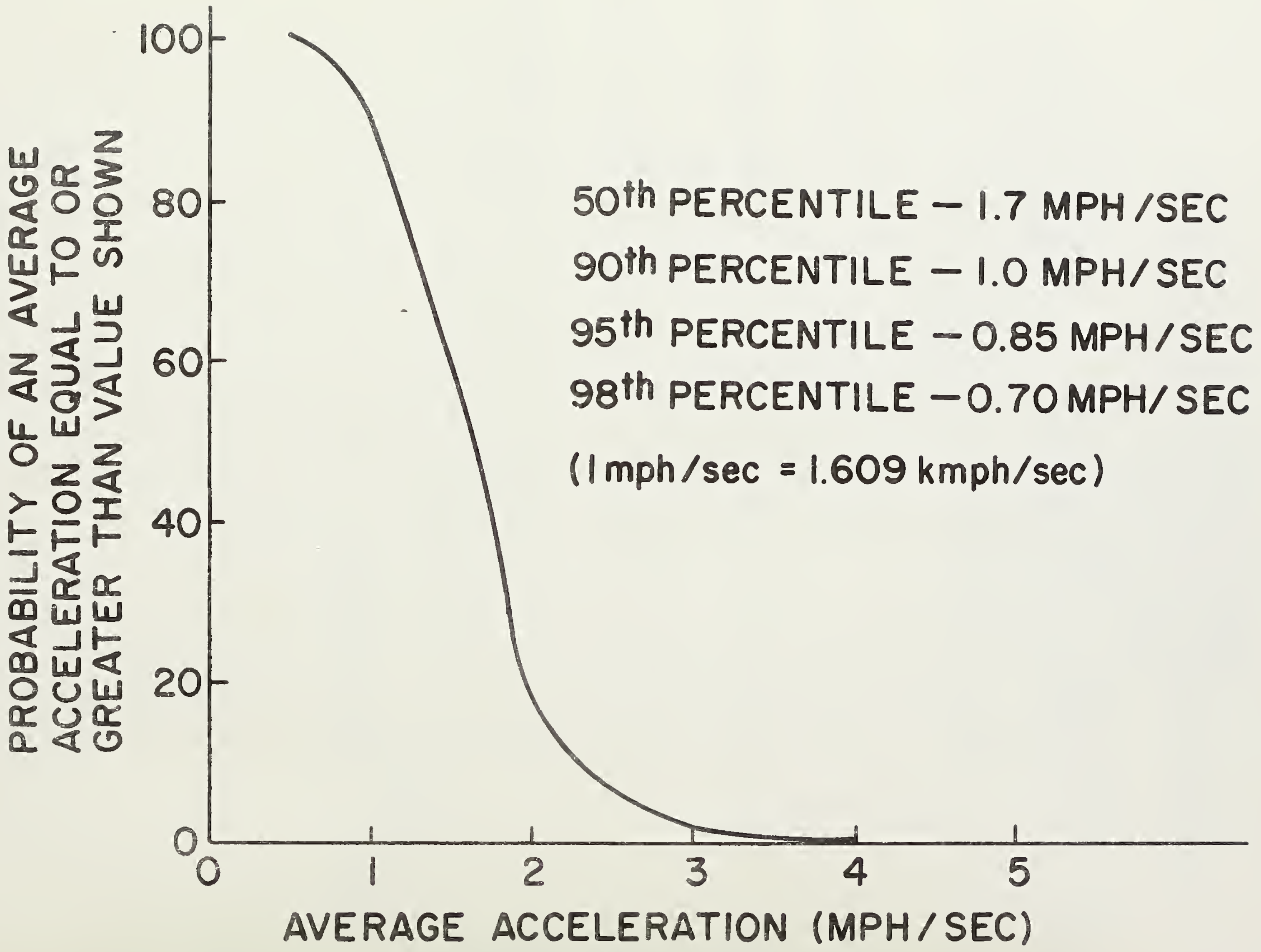


FIGURE 5 ACCELERATION CAPABILITY OF 1976 MODEL VEHICLES (20)

in flagrant disobedience of the no-passing marking. Conversely, leaving the roadway unmarked can lead a driver to expect that sufficient distance is available to permit a safe passing maneuver at reasonable speed. Criteria to determine minimum passing zone lengths logically should be based on acceleration characteristics of passenger vehicles. Obviously, to avoid forcing a passing driver to complete the maneuver beyond the beginning of the next no-passing zone, minimum allowable passing zone length should not be less than the distance in which a representative vehicle can physically pass even a slow-moving vehicle.

Acceleration data and passing distances published by vehicle manufacturers under Federal requirement were used to establish minimum allowable passing zone lengths. Tables 6 and 7 present summarized passing distances for model year 1977 vehicles in performing low-speed and high-speed passing maneuvers respectively. Low speed passes, by federal definition,

TABLE 6

LOW SPEED PASSING DISTANCES FOR 1977 VEHICLES (12)

Distance Group (ft)	Compact and Subcompact Models			Full Size Vehicles			Composite of All Vehicle Types		
	Freq.	Cum. Freq.	Cum. %	Freq.	Cum. Freq.	Cum. %	Freq	Cum. Freq.	Cum. %
375-400	0	0	0	1	1	2.8	1	1	1.9
400-425	7	7	41.2	10	11	30.6	17	18	34.0
425-450	3	10	58.8	20	31	86.1	23	41	77.4
450-475	7	17	100.0	3	34	94.4	10	51	96.2
475-500				2	36	100.0	2	53	100.0
500-525									

Metric Conversion

1 ft = 0.305 m

TABLE 7

HIGH SPEED PASSING DISTANCES FOR 1977 VEHICLES (12)

Distance Group	Compact and Subcompact Models			Full Size Vehicles			Composite of All Vehicle Types		
(ft)	Freq.	Cum. Freq.	Cum. %	Freq.	Cum. Freq.	Cum. %	Freq.	Cum. Freq.	Cum. %
1000-1200				1	1	2.3	1	1	1.6
1100-1200				0	1	2.3	0	1	1.6
1200-1300	2	2	10.5	1	2	4.7	3	4	6.5
1300-1400	2	4	21.1	12	14	32.6	14	18	29.0
1400-1500	4	8	42.1	14	28	65.1	18	36	58.1
1500-1600	3	11	57.9	4	32	74.4	7	43	69.4
1600-1700	2	13	68.4	10	42	97.7	12	55	88.7
1700-1800	2	15	78.9	0	42	97.7	2	57	91.9
1800-1900	3	18	94.7	1	43	100.0	4	61	98.4
1900-2000	0	18	94.7				0	61	98.4
2000-2100	1	19	100.0				1	62	100.0

Metric Conversion

1 ft = 0.305 m

involve a passenger vehicle passing a 20-mph (32.2 km/h) truck [55-ft (16.8 m) length]; high-speed passes involve a 50-mph (80.5 km/h) truck. The passing situation under which the tests must be conducted are specified federally (29). The tables reflect data for all vehicle models but are not weighted according to distribution by type in the vehicle population. Also, distance data reflect "ideal" vehicle operating conditions rather than the reduced vehicle operation that could be expected of the typical automobile on the highway.

The data in Table 6 (shown graphically in Figure 6) reveal that at least 500 ft (152.4 m) are needed to physically pass even a vehicle traveling 20 mph (32.2 km/h). Table 7 indicates that the 85th percentile high-speed passing distance for full-size vehicles is approximately 1700 ft (518 m) and for compact and subcompact vehicles, this distance is increased to 1900 ft (579 m). These data suggest that a driver attempting to perform

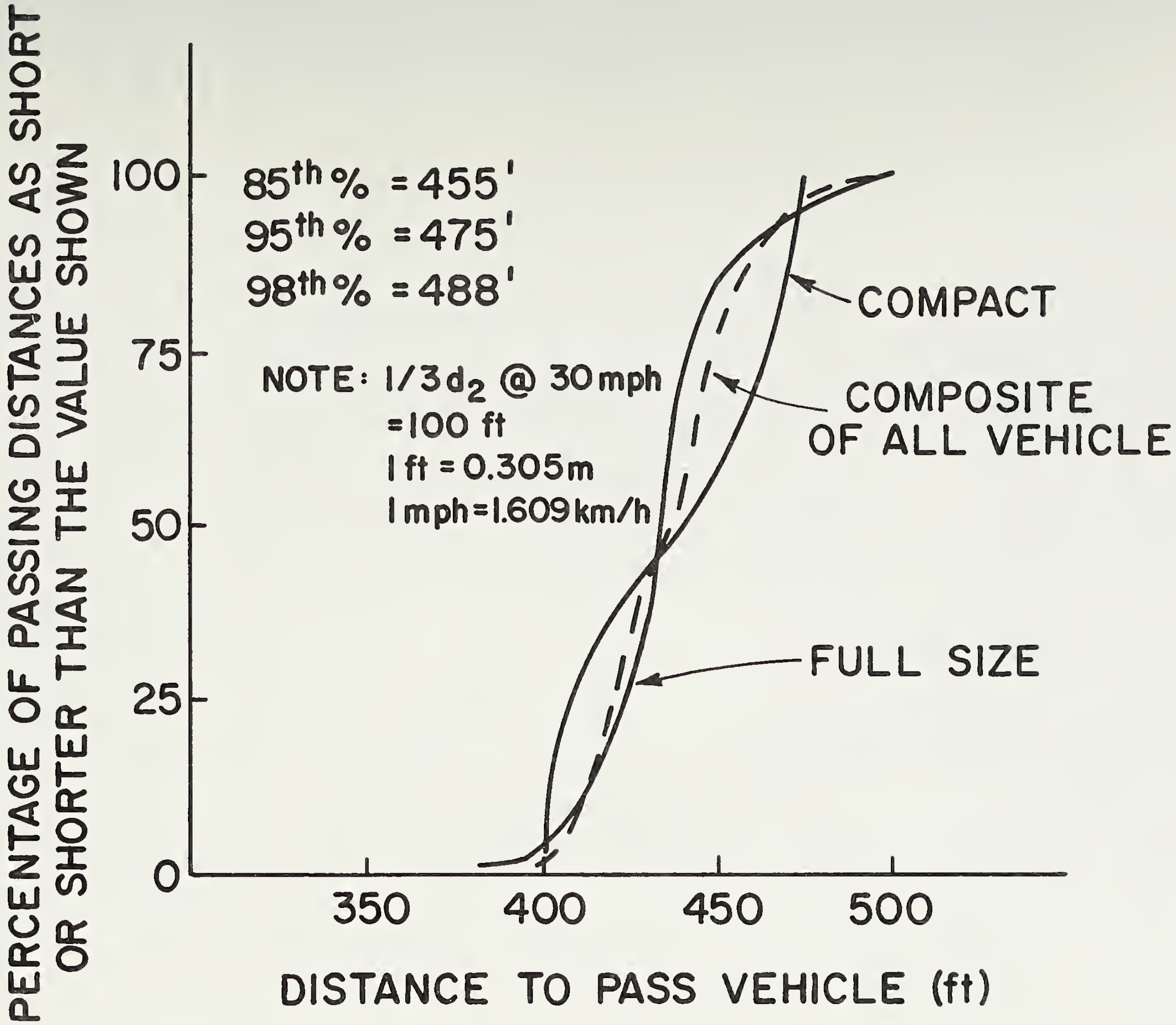


FIGURE 6 LOW-SPEED [20 mph (32.2 km/h)] PASSING DISTANCES EXCLUDING EXIT OR RETURN MANEUVER (12)

a high-speed passing maneuver would experience difficulty in doing so in less than 1500 ft (457 m), and 2000 ft (610 m) would be more desirable. Figure 7 presents high-speed passing distances for vehicle types.

Closure of passing zones less than 2000 ft (610 m) in length would result in an excessively high percentage of existing roadway designated for no-passing, and would not permit the occasional legal low speed passing maneuver. A compromising system is considered to be needed; however such a system must convey clearly to a driver that the passing zone is not of adequate length to complete a high-speed passing maneuver.

VEHICLE CHARACTERISTICS CREATING PROBLEMS FOR DRIVERS

Physical dimensions and operating characteristics have long been used as the sole basis for developing engineering criteria. Often, the driver's assessment of the total situation is not integrated into the criteria establishment process, yet the driver is expected to respond to the system correctly. Drivers were questioned during the human factors laboratory studies to determine problems experienced by them in the performance of the passing maneuver. Presented here are the vehicle-related problems (real or imagined) stated by 126 drivers.

1. Fourteen drivers stated that they intentionally "clipped" the no-passing marking generally only when passing a slow-moving vehicle. Mixing slow and high-speed traffic produces operational problems because drivers become impatient and take chances. Current philosophy considers that all passing responsibility be placed on the passing driver. Although, beyond the scope of this study, consideration toward regulation of slow-moving vehicles in assisting passing by trailing vehicles may alleviate some problems. From a traffic control viewpoint, passing zones must be sufficiently long to physically pass even the larger slower-moving vehicles.
2. Nine drivers stated that they would "jump" the passing zone only to pass slow moving vehicles. It is believed that demarcation systems would not alleviate this action; however, extending the downstream end of the no-passing zone too far might increase this action.

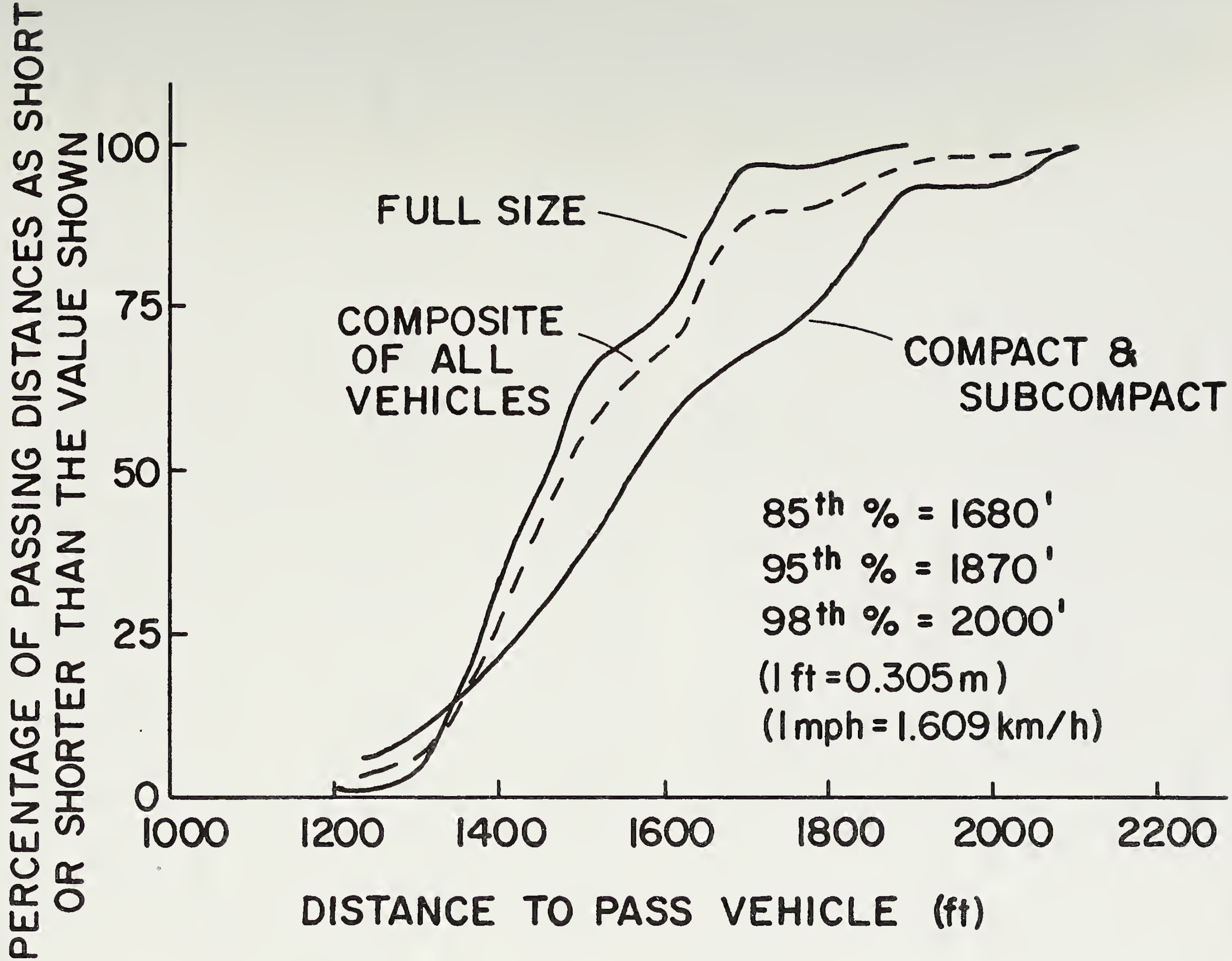


FIGURE 7 HIGH-SPEED [50 mph (80.5 km/h)] PASSING DISTANCES EXCLUDING EXIT OR RETURN MANEUVER (12)

3. Eighteen drivers stated that they "clipped because the passed vehicle sped up during the maneuver thus increasing the passing distance beyond that anticipated. Fifty stated that they would "jump" because they believed this would occur. Field observations (13) indicate that the passed vehicle generally does not speed up; however, reduced vehicle acceleration capabilities at the higher speeds may create false speed differential sensation to drivers. Passing criteria should be based on reasonably selected percentile levels of acceleration capabilities.
4. Nine drivers stated that their vehicles lacked adequate acceleration capabilities to pass in many of the current passing zones.
5. Twenty-six drivers stated that they experienced difficulty in determining the length of available passing zone because they were trailing large vehicles or vehicles traveling near the roadway centerline.
6. Other problem-causing factors included inadequate visibility of approaching vehicles because of low profile or color, inadequate vehicle mirror systems, and wind gusts in passing large trucks.

VEHICLE DIMENSIONS

Since an opposing vehicle during the passing maneuver constitutes the primary hazard, its presence must be perceived at or before the time that either driver is placed in relative position to be unable to avoid collision or take corrective action. A driver's capability to perceive the presence of an opposing vehicle is directly related to his (her) eye height above the pavement and the height of the opposing vehicle (object height).

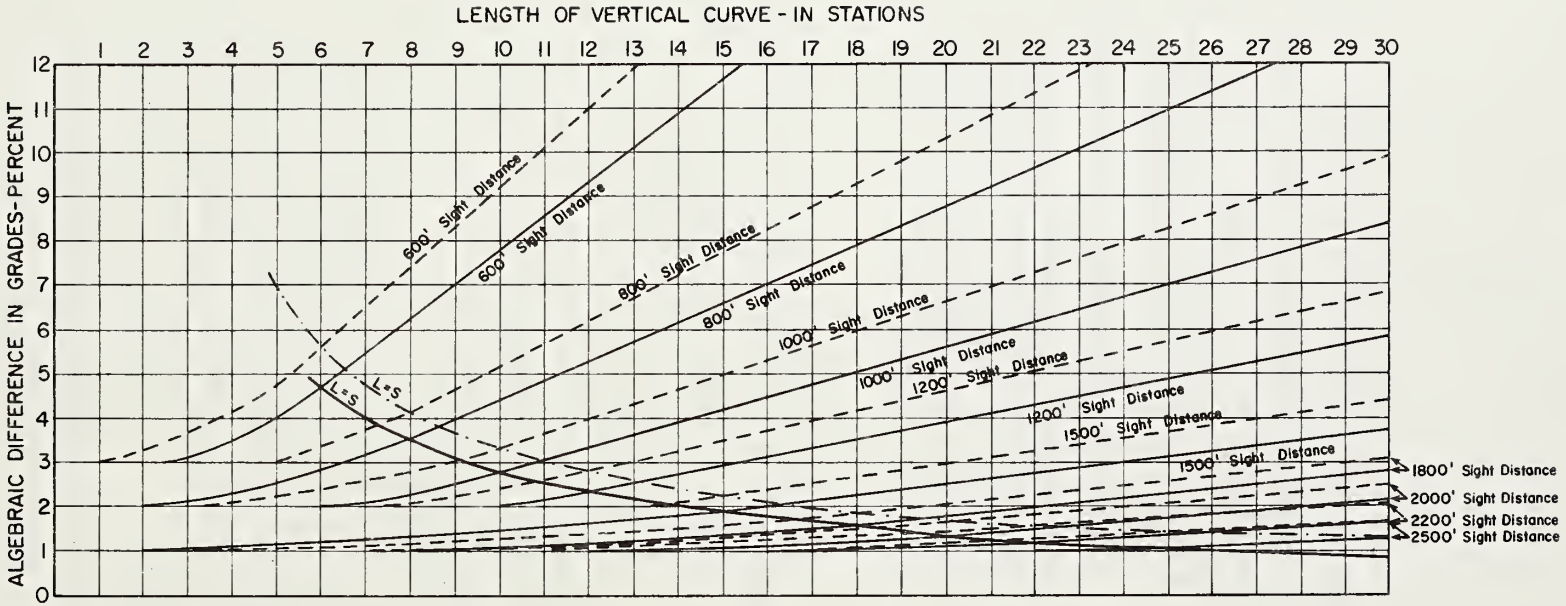
Current engineering practice assumes driver eye height to be 3.75 ft (1.14 m). Although eye height varies considerably among the driving/vehicle population, recent research indicates that this value may be slightly high. A study recently completed (16) and under review by the FHWA Environmental Design and Control Division (ED&C) recommends that driver eye height of 3.5 ft (1.07 m) be used for design purposes. The latest version of the revised AASHTO design policy, currently under review, mentions that the 3.5 ft (1.07 m) height may be more representative of current vehicles; however, because the difference created is so small, the 3.75 ft (1.14 m) height will probably be retained.

Cunagin et al (35) photographed drivers of 161 passenger cars and pick-up trucks as they passed. The sample included 62 small and subcompact automobiles, 86 intermediate and full-size automobiles and 13 pick-up trucks. Eye heights were determined from the photographs. The findings revealed that driver eye heights for 89 percent of the compact and subcompact passenger cars and 73 percent of the intermediate and full-size passenger cars were less than 3.75 ft (1.14 m). The minimum eye height observed in the study was 3.4 ft (1.04 m). The study indicated also that 85 percent of drivers of compact and subcompact passenger cars view the road from a height more than 3.5 ft (1.07 m) with the corresponding 85th percentile eye heights for intermediate and full-size cars being 3.6 ft (1.10 m) and 4.5 ft (1.37 m) for pick-up trucks.

In view of the supportive evidence, it appears that a driver eye height of 3.5 ft (1.07 m) is more representative of the vehicle population and should be used for design purposes. The impact of this with respect to length of crest vertical curve to provide sight distance between two opposing vehicles, as shown by inspection of Figure 8, is relatively small in terms of increased curve length (from about 100 to 300 ft; 30.5 m to 91.4 m); however, the increasing popularity of smaller personal vehicles indicates that the 3.5 ft eye height (1.07 m) will more adequately define driver visual conditions for safety in the near future.

Observations of passenger automobiles indicate that roof-top heights range from about 43 to 55 inches (1.09 to 1.40 m) with the lower height representing extremely low profile "sport-car" vehicles and the upper extreme being representative of full-size sedans and stationwagons. Medium size automobile heights were found to be only slightly lower than the 55-in (1.40 m) height.

It is apparent that a driver must perceive approximately the upper foot (0.305 m) of an opposing vehicle to perceive that it is in fact an automobile. This indicates that an appropriate object height is about



For L<S $L = 2S - \frac{100(\sqrt{2h_1} + \sqrt{2h_2})^2}{A}$

For L>S $L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$

where L = Length of vertical curve, ft.
A = Algebraic difference in grades, %
S = Sight distance, ft.
h_1 = eye height, ft.
h_2 = object height, ft.

LEGEND

——— h_1 = 3.50 ft. and h_2 = 3.50 ft.
- - - - h_1 = 3.75 ft. and h_2 = 4.50 ft.
(1 ft. = 0.305 meters)

FIGURE 8 LENGTH OF CREST VERTICAL CURVE TO PROVIDE TOTAL PASSING SIGHT DISTANCE

42 to 43 inches (1.07 to 1.09 m) or 3.5 to 3.6 ft. It is pointed out that the current 4.5 ft object height (1.37 m) provides visibility to merely the roofline plus about one inch (2.54 cm) of the highest passenger automobile measured. Considering that many vehicles are lower than this height, the use of a 4.5 ft (1.37 m) design vehicle height appears to be too high. It is considered appropriate that for design and marking purposes, the eye and object height should be 3.5 ft (1.07 m).

ROADWAY CHARACTERISTICS INFLUENCING DECISION TO PASS

To supplement the accident analysis findings, human factors studies were designed to elicit information regarding driver's opinion of the influence of certain roadway features on their decision to pass. Included in the initial human factors laboratory studies was a section pertaining to roadway geometric factors that drivers were asked to rank in order of importance in influencing their decision to pass. The studies were conducted in Texas and Iowa. (See Ref. 61 for details of studies).

Crest vertical curves ranked higher in importance than horizontal curves, with horizontal curves to the right being more influential in the passing decision than curves to the left. The greater importance associated with a right curve could be due in part to the reduced visibility caused by the relative alignment of the passing and passed vehicle.

In Texas, it is not uncommon to observe the slower moving vehicle move to the paved shoulder to allow the passing vehicle to pass while remaining in the right travel lane, the passed vehicle then returning to the right travel lane. Interestingly, and contrary to expected response from Texas drivers, the presence of a paved shoulder ranked very low in Texas drivers' decisions to pass, and was ranked last by Iowa drivers. Conversely, shoulders were ranked high in importance by drivers meeting an opposing vehicle passing toward them.

Analysis of the roadway feature results provided a possible reason for the high incidence of intersection-related passing accidents found in the accident file studies. Intersections and driveways on rural highways received a low ranking in all studies. Apparently drivers look for other cues before driveways when deciding to pass, and are, therefore, less likely to detect a vehicle entering the primary roadway or anticipate a turning maneuver by the vehicle they are attempting to pass. It is believed, also, that the expectancy pattern is completely disrupted by the sudden apppearance of a vehicle in a lane that was "clear" only moments before. The concomitant increased reaction time under these circumstances, coupled with drivers' known inability to correctly judge speed, and closure distance and rate, can produce a highly probable collision situation.

Roadway features that are considered to represent degrading influences on safe passing operations because they inhibit visibility are summarized:

1. Horizontal curves exhibit less advance notification of the probability of a no-passing zone than do crest vertical curves. A driver approaching a crest vertical curve receives visual cues from the roadway and skyline in addition to enhanced visibility of a solid yellow line on the upward side of the curve.
2. Hidden "dips" or sag vertical curves that are sufficiently deep to conceal the presence of an opposing vehicle, represent one of the most hazardous situations to a passing driver because in many cases, the roadway geometry is not apparent to the driver. The traffic control devices, therefore, provide the sole source of warning information.
3. Crest vertical curves exhibiting low positive grade on the approach side and high negative grade immediately over the crest produce a potentially hazardous situation similar to the "dip" noted above. The beginning of the no-passing zone generally occurs near the crest, a situation which produces poor visibility characteristics of the painted marking to a driver approaching on the "gentle" upslope.
4. The reverse situation (steep upgrade, gentle downgrade) in crest vertical curves can produce short no-passing zone designation with the marking beginning very near the crest. This situation is considered to be somewhat less hazardous because the marking is slightly more visible due to its more vertical plane.
5. Intersections, although beyond the scope of this study, present driver expectancy problems. Consideration should be given to developing special criteria and warrants for safety at these locations.

CHAPTER 5

HOW DO DRIVER CHARACTERISTICS INFLUENCE THE PASSING MANEUVER?

It is believed that execution of a successful passing maneuver depends for the most part on the judgmental decisions made by the driver. Although practically all driver senses come into play during execution of the passing maneuver to some degree, the predominant sense stimulated is that of sight. Decisions are made on the basis of visual information received and processed in a rapidly changing dynamic situation. Since the driver represents such a critical element in the system, and correct assessment of visual cues is vital to proper response, it is necessary to identify the individual driver tasks performed during the maneuver, determine where and when particular information sources are most needed and evaluate the degree to which various systems provide the visual cues.

Presented in this section is a discussion of driver tasks, an evaluation of work load during each task, and a summary of driver-related problems determined from the human factors studies.

DRIVER TASKS IN PERFORMING A PASSING MANEUVER

The intent of this research was not to conduct detailed human factors analyses of driver work load; however, based on previous such research (36) full driver concentration is considered necessary to accommodate 0.5 activities per second (1 activity per 2 seconds). Work load in excess of this can be expected to produce load shedding to the degree that many activities of lower priority are ignored or accomplished to a lesser degree in conjunction with higher priority actions.

The individual tasks that should be performed in the total passing maneuver were identified and categorized into four primary tasks and average time per activity was computed based on observed times (13) in which the tasks were accomplished.

Task 1 includes 12 discrete activities performed during the d_1 distance in which the driver determines that there is a need to pass, evaluates the relative safety and decides to attempt a passing maneuver. Performing these 12 activities in the 1.64-second d_1 time produces an average time per activity of 0.14 seconds. Driver work load is very heavy during this portion of the maneuver.

In Task 2, the driver maneuvers the vehicle into the left lane, accelerates, re-evaluates the safety of the pass, counter-steers to the right and brings the vehicle to a position centered in the left lane. A total of 25 activities are performed in this 1/3 d_2 distance (3.46 seconds) producing a 0.13-second average time per activity. Driver work load is considered to be very heavy during this portion of the maneuver.

In Task 3, the driver continues to pass the slower vehicle, checking to see if clearance is sufficient, performing 5 activities in 3.46 seconds. The resulting 0.692-second average time per activity is considered to impose a moderate work load.

In Task 4, the driver steers right to return to the right lane then left to center the vehicle in the right lane while checking clearance with the passed vehicle. A normal driving pattern is then established. The 10 activities in 3.46 seconds produce a heavy work load of 0.35-second average time per activity.

This simplified analysis suggests that, during the passing maneuver, the driver is substantially overloaded during Task 1 and 2 and will have little time to search for traffic control information. During Task 3, the work load is reduced slightly, providing a driver more time to search the visual field for traffic control information. Unfortunately, by this point, the driver is fully committed to pass regardless of the traffic control requirements.

In terms of providing the traffic control device visual information at the needed reference point in the maneuver, the above analysis suggests that the information source should be translated upstream to the point of decision where the passing driver can receive it in a timely manner. A second possibility involves providing an information source that is more distinctive in the visual field such as increasing the vertical height of the information source. Several techniques to provide the needed information at the decision point are discussed in detail later in this report.

VISUALLY RECEIVED INFORMATION INFLUENCING DECISION TO PASS

To determine the relative importance in influencing a driver's decision to pass, initial laboratory studies included portions designed to provide a ranked order of visual information sources as stated by drivers (reference number 61). Knowledge of what drivers looked for prior to and during the maneuver was evaluated in terms of how this desired information could best be provided.

As expected, a perceived opposing vehicle was stated by drivers as exerting the greatest influence on the decision to pass or to await another opportunity. Of major importance to this study, traffic control devices including (in order) a solid yellow line, a no-passing zone pennant sign, or both, were cited next as controlling factors in the passing decision. Geometric features of the roadway were rated least important. Drivers in Iowa, where the pennant sign is used extensively, stated that the solid yellow line influenced their decision to pass more so than merely the no-passing zone pennant. Although this finding does not in any way imply that the no-passing zone pennant is not a useful traffic control device it does reinforce the strengths of the more conventionally used marking system, namely driver understanding and confidence in the system.

Drivers also stated that the primary deficiency in the current solid yellow line marking was that they could not detect the beginning of the no-passing zone with sufficient lead-time to complete a legal passing maneuver. Drivers openly stated that many existing passing zones were too short and they believed such zones should be closed up. They preferred that the demarcation system prohibited passing rather than allowing them to initiate a pass only to find out that there was insufficient remaining passing distance.

SUMMARY

The findings from the driver-related phase of the study that were incorporated into the development of criteria and the design of traffic control devices to enhance safety in the passing maneuver are summarized below:

1. A passing driver experiences heavy work load during the portion of the maneuver in which the critical position is reached. Improvements in provision of information that can be perceived during this critical phase should prove most beneficial to the performance of a safe maneuver.
2. Drivers understand the basic yellow solid line as a device to designate prohibition of passing. This understanding and apparent confidence suggest that the concept is basically acceptable and it should be used as the "core" of a traffic control system rather than attempting to institute totally different devices.
3. The primary weakness in the use of the solid yellow line is the poor visibility aspect when viewed from the low driver visual angle. This suggests incorporation of advance notification to alert a driver of the remaining available passing distance.
4. Consideration should be given to establishing minimum passing zone lengths in which a driver can complete the maneuver. Passing zones of insufficient length should be closed up to designate "no-passing."

CHAPTER 6

WHAT ARE DRIVER INFORMATIONAL NEEDS FOR SAFE PASSING OPERATIONS?

The human factors studies (Ref. 61) indicated that practically all drivers interpreted the presence of a solid yellow line to mean that driving to the left of the line was illegal and unsafe, and that passing maneuvers should be completed before reaching the solid line. This driver interpretation conforms to the short zone concept of designating no-passing zones -- the intended operation of the short zone no-passing concept is that, after passing the slower vehicle, the passing vehicle should return to the right lane before reaching the beginning of a no-passing zone; in other words passing operations should be initiated and completed within a legal "passing zone." No-passing zones designated under this concept are established when sight distance decreases below those values specified in the MUTCD. Conversely, the long zone concept permits completion of a passing maneuver beyond the beginning of the marked no-passing zone; however, the sight distances used under this concept are longer than those used for the short zone concept, thus a "buffer zone" is provided at the upstream end of the no-passing zone. State practice investigation (see Chapter 8) revealed that no states use the long zone concept per se to designate no-passing zones, although five permit completion of the maneuver beyond the start of the solid yellow line. The important fact here is that the States permitting this operation mark the no-passing zones using short-zone sight distance criteria, not long zone criteria; therefore, the "buffer zone" which is the primary attribute of the long zone concept is not provided.

The short zone concept and concomitant operations is preferred by enforcement personnel because it designates a discrete location where a passing driver should return to the right lane, alleviating, to a large degree, the subjectiveness in determining driver violation (19). Police in attendance at the enforcement workshop conducted as a part of this study (19) agreed unanimously that a primary operational deficiency in the short zone system, however, was related directly to inadequate information cues to advise a passing driver of the available passing distance beyond the point of initiation of the maneuver. The problem pertains to a passing maneuver whether it is initiated at the beginning of the designated passing zone or at some position within the passing zone. Obviously, the criticality of the situation increases as the maneuver is initiated closer to the downstream end of the passing zone.

The informational needs to satisfy safe passing operations proposed in this study are based on the analysis of vehicle operations (Chapters 3 and 4), results of the driver practices human factors studies (Ref. 61), the defined "critical passing maneuver" (Chapter 3), and the basic premise of short zone application. They are used as a base to which satisfaction of existing design and marking practices are evaluated and for which recommended criteria and traffic control devices are developed.

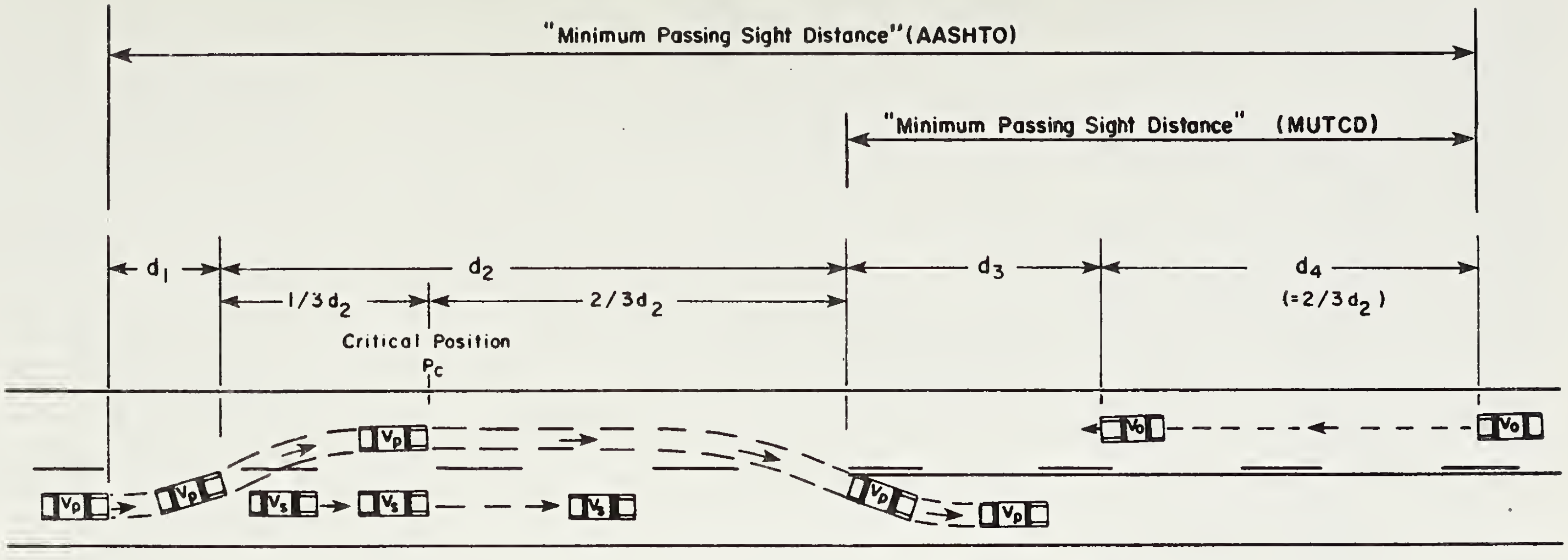
Essentially, two informational sources represent the total visual needs of a passing driver: (1) the perceived presence of an opposing vehicle, and (2) an indication of the available legal passing distance remaining beyond any point within the maneuver. Passing practice has, conventionally, been conceived as a "negative" traffic control situation based on the premise that drivers should be informed where passing is prohibited and where not so informed, they may pass if the maneuver can be accomplished safely. Drivers accept this philosophy; in fact, state that they prefer to be vividly informed when passing should not be attempted. To maintain uniformity and alleviate personal judgment of safety, it is strongly believed that for this particular maneuver, "negative" control represents the proper control approach. The serious flaw appears to be that drivers can make positive decisions only after mentally transforming "negative" information. The perception of an opposing vehicle is positive information that may be immediately translated into "negative" response -- abort the maneuver if the vehicle is too close; or "positive" response -- complete the maneuver if the assessed clearances will be sufficient. The outcome of either response could be extremely hazardous, or of less serious consequence, illegal, if the driver is not made aware that there is a point in the passing zone beyond which he should not be passing if he has not already reached the "critical" position. By designating this location, the transition can be made between negative and positive information and physical identification of this point greatly ameliorates known inability to correctly judge speed and closure distance and rates. This concept, if implemented in a manner that drivers will easily learn and immediately recognize, may be used to define the last downstream point that a passing maneuver may be safely initiated without continued reliance on a drivers capability to identify the point at which the passing maneuver must be completed. If the location is established on the basis of needed operating distance (and concomitant sight distance to an opposing vehicle) to complete the maneuver from the "critical" position for a specified operating speed, the driver may be assured that there always remains sufficient safe passing distance ahead if he has not reached the designated point in the passing zone. The concept presented here translates the current negative information source -- the beginning of the next no-passing zone by which he must have completed the maneuver -- to a positive source meaning that, "until reaching this location, a driver has sufficient remaining distance to complete a passing maneuver; beyond it there is insufficient distance without encroaching on an upcoming prohibitive zone." The highly favorable aspect of such a concept is that it is independent of passing zone length and can be used effectively to advise drivers that the passing zone is short.

The above "advance notification" concept is developed in the remaining sections of this report including distance requirements for location of the critical point within the passing zone, types of traffic control devices to implement it, evaluation of current practice in providing the needed information, from which modifications to existing policy and guidelines to legalize its implementation may be developed.

CHAPTER 7

WHAT ARE CURRENT DESIGN AND MARKING PHILOSOPHIES?

Existing criteria for design of "passing sight distance" (21) and warrants for placing no-passing zones on completed highways (3) are established on different assumptions -- not necessarily on different operational distances, but primarily different assumptions of what is considered desirable in providing roadway sight distance at the design stage for a chosen operational level and what is considered absolutely minimum roadway sight distance to permit passing operations because opposing vehicles could not safely avoid collision. Both criteria, essentially, are based on observed vehicle operations (distances, times, accelerations, etc.) during the passing maneuver (10) however, the two concepts differ in the manner in which the distance elements are combined to define "passing sight distance." The two philosophies produce what at first review appear to be greatly different "passing sight distance" minimum values for a given operating speed. Several problems occur due to the two concepts with the inevitable question arising, "why are certain distances specified for design when substantially lesser distances are used to denote unsafe passing zones?" In essence, this question is challenging both concepts -- "are design distances unrealistically conservative or are marking criteria unrealistically lenient?" Neither may be the case; however, the terminology "minimum passing sight distance" may be blamed for creating part of the apparent disparity since both concepts use this terminology yet apply the terminology to different combinations of distance elements within the passing maneuver. Figure 9 illustrates the distance elements comprising the physical execution of the passing maneuver (the operational distance necessary to travel around the slower moving vehicle) and the sight distance downstream that must be available during this maneuver if the passing driver is to be able to perceive an opposing vehicle in time to complete the maneuver with a suitable clearance distance. The combinations of these elemental distances comprising the design and operational (marking) defined "minimum sight distance" are superimposed on Figure 9 to illustrate the roadway distance differences for these identically named terms.



Note: Opposing Vehicle Appears
at Point B When Passing
Vehicle Reaches Point A.

FIGURE 9 COMPARISON OF AASHTO AND MUTCD DEFINITION OF "MINIMUM PASSING SIGHT DISTANCE"

The important fact that must be clearly understood is that, regardless of terminology, the sight distances are specified from two different reference points within the passing maneuver -- "design" distances encompass the total distance elements ($d_1 + d_2 + d_3 + d_4$) which include physical maneuver operating distance ($d_1 + d_2$) and sight distance ($d_3 + d_4$), the summation of which are termed "minimum passing sight distance." "Marking" distance applies only to the sight distance elements $d_3 + d_4$ which represents a rather arbitrarily selected sight distance that a passing driver must be provided to perceive an opposing vehicle because of a commitment to completing the maneuver. The rationale of combining particular distance elements for the different functions is discussed below.

The design philosophy is that if total sight distance throughout the entire maneuver is provided at the beginning of a passing opportunity, a driver may sequentially execute each element comfortably with full visual knowledge throughout the complete maneuver of the presence of an opposing vehicle that may be within the required passing distance and allow adequate separation distance between the two opposing vehicles at the completion of the maneuver. Provision of sight distance to permit this type of operation represents a desirable design objective. Provision of less available sight distance than this will necessarily produce less than the desirable design.

The amount of available sight distance can be decreased below this total distance value until a point at which sight distance ahead becomes less than that necessary to perceive an opposing vehicle in time to safely complete a passing maneuver once the driver is committed to the execution of the maneuver. This, in essence, predicates "minimum passing sight distance" and forms the basis of the marking sight distance definition.

Although the AASHTO design criteria (21) and the marking warrants (3) are documented in other publications, they are summarized in Table 8 for ready reference. The distance elements comprising the two criteria are evaluated in subsequent sections of this chapter because they represent the operational parameters by which the maneuver may be defined. After the distance elements are quantified the only problem remaining concerns the choice of combination of the elements to provide safe operations and the acceptance of defining terminology.

TABLE 8
COMPARISON OF "MINIMUM SIGHT DISTANCES" FOR DESIGN AND MARKING

85th Percentile Speed (mph)	Minimum Sight Distance (ft)		
	Design (21)	Marking (Short Zone)(3)	(Long Zone)(2)
40	1500	600	1050
50	1800	800	1300
55	1950	900*	1450
60	2100	1000	1600
70	2500	1200	1900

* Interpolated value

Metric Conversion

1 mph = 1.609 km/h
1 ft = 0.305 m

EVALUATION OF DISTANCE ELEMENTS IN AASHTO DESIGN MODEL

Table 9 presents a summary of the distance elements measured by Weaver and Glennon (13) in a 1971 study of vehicle performance during passing maneuvers on two-lane highways. Review of these data reveals that except for the very low-speed maneuvers, the AASHTO design total distances do not differ appreciably from those measured by Weaver and Glennon. This disparity at the low speed maneuver could be due to extrapolation of the regression curves; however, it is of no significance to practical usage because design is not generally predicated on such a low operating speed. The most significant factor is that for all speeds except the 70 mph (113 km/h) speed, AASHTO design total distances are greater than those determined by Weaver and Glennon. Thus the current design distances generally are somewhat conservative for modern vehicles.

TABLE 9 PASSING DISTANCE ELEMENTS

(Col. 1)	(Col. 2)	(Col. 3)	(Col. 4)	(Col. 5)	(Col. 6)	(Col. 7)	(Col. 8)	(Col. 9)	(Col. 10)	(Col. 11)	(Col. 12)
Expected 85th Percentile Speed (mph)	d_1 (ft)		d_2 (ft)		d_3 (ft)		d_4 (ft)		Total d (ft)		
	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO Actual	AASHTO Design Values
40	96*	215	486*	640	138*	180	246*	425	966*	1460	1500
50	193	290	692	825	211	250	410	550	1506	1915	1800
55	241	330	794	930	248	275	492	615	1775	2150	1950
60	289	370	896	1030	285	300	574	680	2044	2380	2100
70	386	NA	1100	NA	359	NA	739	NA	2584	NA	2500

* Extropolated from regression curves (4)

Metric Conversion

1 ft = 0.305 m

1 mph = 1.609 km/h

The assumptions on which the maneuver is described in the AASHTO model were found by Weaver and Glennon to be generally valid for modern vehicles. The Weaver and Glennon measured distances are used throughout this report to define criteria for safe passing operations because these data represent the most current vehicle performance data and are assumed to more closely reflect current vehicle operations than do the AASHTO data.

PASSING TIME COMPARISON

The current design model assumes a 1.5 mphps (2.41 kmph/sec) acceleration rate. As shown earlier (Ref. Chapter 4), modern vehicles, even compact models, exhibit acceleration capabilities well above this level; however, it is realized that the design process should accommodate a high percentage of all vehicles. The assumed 10 mph (16.1 km/h) speed differential passing situation presented in Chapter 4 assumes a 1.0 mphps (1.61 kmph/sec) acceleration rate which represents the 90th percentile level. Under this assumption, using the AASHTO equations for the d_1 distance element, and substituting the d_1 values measured by Weaver and Glennon, a modified value for time t_1 may be computed as shown below:

$$d_1 = 1.47\ t_1\ (V - m + \frac{at_1}{2})$$

$$d_1 = 1.47\ t_1\ (V - 10 + \frac{t_1}{2})$$

Solving for t_1,

$$t_1 = \left[\frac{2d_1}{1.47} + (V - 10)^2\right]^{\frac{1}{2}} -V + 10$$

The corresponding t_1 - values from the above equation are shown in Table 10 (Column 4) for the operating speeds selected.

Weaver and Glennon (13) developed equations for speed-distance relationships in the passing maneuver as shown below:

$$d_1 = 9.655\ V - 290.111$$

$$d_2 = 20.408\ V - 328.811$$

TABLE 10

TIME REQUIRED TO EXECUTE THE PASSING MANEUVER

(Col. 1)	(Col. 2)	(Col. 3)	(Col. 4)	(Col. 5)	(Col. 6)	(Col. 7)	(Col. 8)	(Col. 9)	(Col. 10)	(Col. 11)	(Col. 12)	(Col. 13)
Expected 85th Percentile Speed (mph)	t_1 (sec)			t_2 (sec)		t_3 (sec)		t_4 (sec)		t_{total} (sec)		
	Weaver & Glennon	AASHTO	10 mph* Speed Assumption	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO	Weaver & Glennon	AASHTO	10-mph Speed Assumption
40	1.64	3.6	2.10	8.29	9.3	2.34	1.94	4.19	6.14	16.46	20.98	19.48
50	2.62	4.0	3.15	9.41	10.0	2.88	2.80	5.59	6.60	20.50	23.40	22.55
55	2.95	4.2	3.51	9.78	10.4	3.02	3.02	6.06	6.85	21.81	24.47	23.78
60	3.28	4.3	3.79	10.15	10.7	3.23	3.23	6.52	7.10	23.18	25.33	24.82
70	3.75	4.5	4.23	10.68	11.3	3.49	3.29	7.18	7.45	25.10	26.54	26.27

*Note: t_1 time is based on assumption of a 1 mphps acceleration rate throughout distance d_1

Metric Conversion

1 mph = 1.609 km/h

$$d_3 = 7.38\ V - 157.56$$

$$d_4 = 16.430\ V - 411.156$$

$$d_{total} = 53.873\ V - 1187.998$$

where

d = distance, ft (1 ft = 0.305 m)
V = vehicle speed, mph (1 mph = 1.609 km/h)

Assuming a constant speed differential, $d_i = Vt_i$ where t_i is the time required for each element, and solving the above equations for t_i, the average time for each element may be calculated as follows:

$$t_1 = 6.57 - \frac{290.11}{1.47V}$$

$$t_2 = 13.88 - \frac{328.811}{1.47V}$$

$$t_3 = 5.02 - \frac{157.6}{1.47V}$$

$$t_4 = 11.18 - \frac{411.156}{1.47V}$$

$$t_{total} = 36.65 - \frac{1187.998}{1.47V}$$

where t = time, seconds
V = vehicle speed, mph (1 mph = 1.609 km/h)

The times required for each distance element are shown in Table 10 (Columns 2, 5, 7, 9, and 11).

Reviewing the total time required to execute the passing maneuver it is apparent that use of 1.0 mphps (1.61 kmph/sec) acceleration rate instead of the 1.5 mphps (2.41 kmph/sec) rate alters the AASHTO times only slightly. The resulting times for all speeds higher than 40 mph (64.4 km/h) are only about 10 percent larger than those measured by Weaver Glennon.

MODEL TO DEFINE THE PASSING MANEUVER

In terms of total passing time, elemental and total distances, and positional relationships of vehicles with respect to each other throughout the phases of the maneuver, all three models -- the AASHTO model, the passing-time model, and the Weaver and Glennon model (13) -- produce similar results when used to define the passing maneuver. Also, all three models will accommodate practically every classification of passenger vehicles on the highway as indicated by the insensitivity of the maneuver to vehicle acceleration as discussed above. For practical purposes, any of the three models can be used to define the maneuver. As discussed earlier in Chapter 4, the use of a 3.5 ft (1.07 m) eye and object height is advocated in passing sight distance determination. Also, use of the Weaver and Glennon distance elements are advocated only because they represent the most current vehicle operational data.

CURRENT DISTANCE CRITERIA FOR MARKING NO-PASSING ZONES

Whereas desirable design of a highway would provide sight distance as discussed previously to permit full visual capability throughout the complete maneuver, warrants for designation of no-passing zones (3) are based on the assumption that passing must be prohibited when at best, even the critical completion phase of the maneuver cannot be safely completed because visibility to an approaching vehicle is less than adequate.

Table 11 restates, for reference, the warrants on which no-passing zones are designated. The beginning of a no-passing zone is established when sight distance first becomes less than the Table 11 value and the end of the zone is established when the sight distance again becomes greater than the value specified.

It is evident, from the data in Table 11, that no-passing zone warrants are based on absolutely minimum critical operating conditions. Although the MUTCD does not specify the rationale on which the sight distances are predicated, it is generally accepted that they represent approximately the sum of d_3 and d_4 (AASHTO). The MUTCD values, sum of d_3 and d_4 (AASHTO) and the distance necessary to complete the manuever from the critical position ($2/3d_2 + d_3 + d_4$) from Weaver and Glennon's study are listed in Table 12 for comparison.

TABLE 11

CURRENT WARRANTS FOR NO-PASSING ZONES (3)

85th Percentile Operating Speed (mph)	Minimum Sight Distance (ft)
30	500
40	600
50	800
60	1000
70	1200

Metric Conversion

1 mph = 1.609 km/h

1 ft = 0.308 m

TABLE 12

SUMMARY OF PASSING SIGHT DISTANCES

(Column 1) 85th Percentile Operating Speed (mph)	(Column 2) $d_3 + d_4$ (AASHTO)(21) (ft)	(Column 3) MUTCD (3) Minimum Distance (ft)	(Column 4) $2/3\ d_2 + d_3 + d_4$ (13) (ft)
40	625	600	710
50	800	800	1085
60	980	1000	1221
70	1150	1200	1835

Metric Conversion

1 mph = 1.609 km/h

1 ft = 0.305 m

Further inquiry regarding the basis for establishment of minimum sight distances for marking no-passing zones produced the explanation presented below (40).

The accepted minimum sight distances on which to base pavement markings to indicate no-passing zones are developed as shown below:

	*V				
	30	40	50	60	70
m	10	12.5	15	20	25
V_o	25	32.5	40	47.5	55
Sight distance for flying pass	440	550	660	660	660
Sight distance for delayed pass	510	760	1090	1380	1780
Suggested minimum sight distance	500	600	800	1000	1200

Where V = *The assumed design speed of the road (mph).*

m = *Difference in speed between the assumed design speed and the assumed speed of the overtaken vehicle.*

V_o = *The assumed speed of an opposing vehicle which comes into view just when the passing maneuver is begun.*

Thus on a 50 mph design speed road the passing maneuvers in which the overtaken vehicle travels slower than 35 mph and the opposing vehicle travels slower than 40 mph are assumed to be so infrequent that their restriction by striping will not be of consequence.

The type of pass influences the required passing sight distance appreciably. The assumption of delayed passing is on the safe side but if a road is striped on this basis it may unduly impair the usefulness of the road because vehicles naturally pass without first reducing speed when the opposing traffic lane is clear of vehicles. The suggested sight distances for no-passing zone striping are compromises between the two types of passes.

**Note: The MUTCD uses V = 85-percentile speed and not assumed design speed as was used in the original development of the values described above.*

EVALUATION OF NO-PASSING ZONE WARRANTS

It is evident that the minimum sight distances currently specified for establishment of no-passing zones are not sufficient to allow unobstructed visual capability during completion of the passing maneuver from the critical position -- a requirement that is assumed herein (see Chapter 3) to represent absolute "minimum" safe passing operations. This is not to be misinterpreted to infer that the sight distance at the beginning of the solid yellow line under current criteria is inadequate; it is important to recognize that the sight distance requirement for safety should not be measured at the beginning of the barrier stripe -- it should be provided back at the critical position where the decision must be made to complete or abort the maneuver. The fact that current marking criteria are predicated on sight distance requirements at the completion of the maneuver (short zone concept) coupled with the demonstrated poor visibility characteristics of current demarcation systems from which drivers must judge available passing distance, the current criteria and method of designating the no-passing zone constitute a potentially hazardous conflict situation.

Suggested minimum sight distances for designating no-passing zones and traffic control devices to satisfy the driver informational needs are presented in Chapter 9 of this report. Chapter 10 presents suggested improvements for the design of passing and no-passing zones.

CHAPTER 8

WHAT ARE CURRENT STATE PRACTICES?

The development of criteria for the design of highways has been an evolutionary process over the past half-century. During this period, warrants have been developed with which to install traffic control devices along the roads. In time, the warrants were revised as technology in vehicle design and highway construction improved. In conjunction with this changing process, laws and ordinances were established and subsequently modified. Emphasis has been redirected toward improving driver guidance systems and providing "safety." Throughout all, enforcement goals and procedures have been developed to maintain driver conformance to road rules and traffic control device intent. The result is that there exists considerable diversity, on a national scale, in the manner in which individual States design highways, install traffic control devices, draft and interpret State statutes, and enforce traffic operations.

One phase of this study was directed toward summarizing State practices within these four categories in regard to the passing/no-passing design and demarcation process. Investigation of individual practices in marking, signing or otherwise denoting no-passing zones, for example, would identify unique systems that might exhibit desirable improvements that could be incorporated into current criteria and warrants. Investigation of marking practices would reveal which line widths, and which line patterns (1, 2 or 3-line) were used so that if new longitudinal markings were developed, they could be designed to be compatible with general usage. With the current emphasis on State liability for alleged non-conformance with traffic control device warrants, it becomes important to identify what constraints the accepted laws contain and how individual practices conform or differ before revised laws can be established.

Data obtained by the Federal Highway Administration concerning State practice in designating no-passing zones were supplied for use in this research study. Since the data were collected several years ago, considerable changes have occurred in the designation of no-passing zones, particularly regarding increased usage of the no-passing zone pennant sign. Also, due to economic constraints, many State agencies have reduced the pavement line width and decreased the stripe-to-gap ratio to conserve paint costs. The FHWA-supplied material was used in its original form for the most part to summarize State practices; however, where information became available, the data were updated to reflect more current practice. Additional questionnaires were not administered to the State agencies during this study. Recent changes were determined through personal contact with State agencies and review of published literature during conduct of this and other ongoing research.

STATE PRACTICE INFORMATION

The furnished information on State practice is summarized by State in Table 13 in the categories listed:

(1) No-passing zone marking concept used (short zone or long zone concept),
(2) Minimum spacing between successive no-passing zones,
(3) Use of regulatory signs at beginning and end of no-passing zones either as a statewide practice or under selective usage,
(4) Use of the NO-PASSING ZONE pennant sign as a statewide practice or under selective usage,
(5) Design criteria used,
(6) Criteria used for establishing no-passing zones,
(7) Special or innovative practice or criteria used to establish no-passing zones,
(8) Pavement marking line pattern used,
(9) Maintenance schedules for markings and signs.

In addition to the information categorized above, cost information concerning application and maintenance of markings and signs applicable to no-passing zone designation was obtained. Cost data are summarized in Chapter 11 with corresponding economic analyses of the proposed no-passing zone treatments.

The alphabetical and numerical notes shown in parentheses in Table 13 are discussed in the following section of this chapter.

TABLE 13

SUMMARY OF STATE PRACTICE CONCERNING NO-PASSING ZONES

State	FHWA Region	No-Passing Zone Marking Concept	Minimum Length Between No-Passing Zones (ft)	Uses Regulatory Signs At Beginning of No-Passing Zones		Uses Regulatory Signs At End of No-Passing Zones		Uses No-Passing Zone Pennant (W14-3)	
				Statewide	Selectively	Statewide	Selectively	Statewide	Selectively
Alabama	4	Short	400		R4-1		R4-2	X (a)	
Alaska	10	Short	400		R4-1 (1)		R4-2 (1)	N.S.	N.S.
Arizona	9	Short	400 (1)	N.S.	N.S.	N.S.	N.S.	X	
Arkansas	6	Short	400	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
California	9	Short	(1)	None	None	None	None		X (2)
Colorado	8	Short	400	None	None	None	None	None	(1)
Connecticut	1	N.S.	400		R4-1	N.S.	N.S.	N.S.	N.S.
Delaware	3	N.S.	400	None	None	None	None	N.S.	N.S.
Florida	4	Short	400	N.S.	N.S.	N.S.	N.S.		N.S.
Georgia	4	Short	400	(1)	N.S.	N.S.	N.S.		X (c)
Hawaii	9	Short	400 (1)	None	None	None	None	None	None
Idaho	10	Short	400	R4-1 (1)		R4-2 (1)			X (2)
Illinois	5	Short (1)	400	R4-1		R4-2		X	
Indiana	5	Short	400	R4-1		R4-2		X	
Iowa	7	Short	400	None	None	None	None	X	
Kansas	7	Short	400	R4-1 (1)		R4-2 (2)			X (3)
Kentucky	4	Short	400 (1)	R4-1		R4-2 (3)		X	
Louisiana	6	Short (1)	400		R4-1		R4-2		X (c)
Maine	1	Short (1)	400	N.S.	N.S.	N.S.	N.S.	None	None
Maryland	3	Short	400	N.S.	N.S.	N.S.	N.S.		X (a)(b)
Massachusetts	1	N.S.	400		R4-1		R4-2		X (b)
Michigan	5	Short	400		R4-1		R4-2	X	
Minnesota	5	Short	400		R4-1		R4-2	X	
Mississippi	4	Short	400		(1)		N.S.		X (a)
Missouri	7	Short (1)	400	None	None	None	None	None	None
Montana	8	Short	600					X	
Nebraska	7	Short	750		R4-1 (1)		R4-2 (2)	X	
Nevada	9	Short	400	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
New Hampshire	1	Short	400		R4-1 (1)	N.S.	N.S.	X	
New Jersey	1	Short	400	N.S.	N.S.	N.S.	N.S.		X (c)
New Mexico	6	Short	400		R4-1		R4-2	X	
New York	1	Short	400 (2)		R4-1		R4-2		X (b)
North Carolina	5	Short	400	N.S.	N.S.	N.S.	N.S.		
North Dakota	8	Short	400	(1)	(1)	N.S.	N.S.	N.S.	N.S.
Ohio	5	Short	400		R4-1		R4-2		X (c)
Oklahoma	6	Short	400		R4-1		R4-2	None	None
Oregon	10	Short	400		R4-1 (1)		R4-2 (1)	N.S.	N.S.
Pennsylvania	3	Short (1)	400	(2)		(2)		X	
Rhode Island	1	Short	400	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
South Carolina	4	Short	400	None	None	None	None		(1)
South Oakota	8	Short	400	N.S.	N.S.	N.S.	N.S.	X	
Tennessee	4	Short	400	N.S.	N.S.	N.S.	N.S.	X	
Texas	6	Short	400	(1) (2)	R4-1		R4-2		X (c)
Utah	8	Short	400		R4-1		R4-2		X (c)
Vermont	1	Short (1)	600 (1)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Virginia	3	Short	400		(1)		(1)		X (b)
Washington	10	Short	400		R4-1 (1)		R4-2 (1)		X (c)
West Virginia	3	Short	400	N.S.	N.S.	N.S.	N.S.		X (c)
Wisconsin	5	Short	(1)	R4-1 (2)		R4-2 (3)		X (4)	N.S.
Wyoming	8	Short	400	None	None		R4-2 (3)	N.S.	N.S.

Note: N.S.--"Not Stated"

Metric Conversion:

1 ft = 0.305 m

TABLE 13 (Cont'd)

SUMMARY OF STATE PRACTICE CONCERNING NO-PASSING ZONES

State	FHWA Region	Design Criteria	Demarcation Criteria	Special Practice or Criteria	Pavement Marking System	Pavement Marking Line Width (in)	Marking Maintenance	Sign Maintenance
Alabama	4	AASHTO	MUTCD	-	2-line	4	Annually	As Needed
Alaska	10	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Arizona	9	AASHTO	MUTCD	-	2-line	4	N.S.	N.S.
Arkansas	6	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
California	9	N.S.	MUTCD	(3)	1 & 2-line	4	N.S.	N.S.
Colorado	8	N.S.	MUTCD	-	2-line	5	N.S.	N.S.
Connecticut	1	N.S.	(1)	(1) (2) (3)	2-line	4	(4)	(5)
Delaware	3	AASHTO	MUTCD	-	2-line	4	N.S.	N.S.
Florida	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Georgia	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Hawaii	9	(2)	MUTCD	-	2-line	4	N.S.	N.S.
Idaho	10	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Illinois	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Indiana	5	N.S.	MUTCD	-	2 & 3-line	4 & 6	N.S.	N.S.
Iowa	7	N.S.	MUTCD	-	2-line	4 & 4.5	N.S.	N.S.
Kansas	7	N.S.	MUTCD	-	2-line	5	As Needed	As Needed
Kentucky	4	N.S.	MUTCD	(2)	2-line	4	Annually	As Needed
Louisiana	6	N.S.	MUTCD	-	2-line	4	Annually	As Needed
Maine	1	AASHTO	MUTCD	-	2-line	4 & 6	Annually	As Needed
Maryland	3	N.S.	MUTCD	-	2-line	4 & 5	Annually	As Needed
Massachusetts	1	N.S.	MUTCD	-	2-line	4 & 6	N.S.	N.S.
Michigan	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Minnesota	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Mississippi	4	N.S.	MUTCD	(2)	2-line	4	Annually	As Needed
Missouri	7	N.S.	MUTCD	(2)	2-line	4	6-month	N.S.
Montana	8	N.S.	MUTCD (1)	-	2-line	4	N.S.	N.S.
Nebraska	6	N.S.	MUTCD (3)	(3)	2-line	4	N.S.	N.S.
Nevada	9	AASHTO	MUTCD	-	2-line	4	N.S.	N.S.
New Hampshire	1	N.S.	MUTCD	-	2-line	4	Annually	As Needed
New Jersey	1	(1)	MUTCD	(1) (2)	2-line	4	Annually	As Needed
New Mexico	6	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
New York	1	N.S.	MUTCD	(1)	2-line	4 & 6	N.S.	N.S.
North Carolina	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
North Dakota	8	AASHTO	MUTCD	-	2-line	4	Annually	N.S.
Ohio	5	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Oklahoma	6	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Oregon	10	N.S.	MUTCD (2)	-	2-line	4	N.S.	N.S.
Pennsylvania	3	AASHTO	MUTCD	-	2-line	4	6-month	N.S.
Rhode Island	1	N.S.	MUTCD	-	N.S.	N.S.	N.S.	N.S.
South Carolina	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
South Dakota	8	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Tennessee	4	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Texas	6	Texas (3)	MUTCD	(3)	2-line	4	(4)	(5)
Utah	8	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Vermont	1	N.S.	(1)	(2)	2-line	4	N.S.	N.S.
Virginia	3	N.S.	MUTCD	(1)	2-line	4	N.S.	N.S.
Washington	10	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
West Virginia	3	N.S.	MUTCD	-	2-line	4	N.S.	N.S.
Wisconsin	5	N.S	(1)(5)	(5)	2-line	4	Annually	(6)
Wyoming	8	N.S.	MUTCD (1)	(1)(2)	2-line	4	Annually	N.S.

Note: N.S.--"Not Stated"

Metric Conversion:

1 in = 25.4 mm

REFERENCE NOTES FROM TABLE 13

The special notes identified in parentheses in Table 13 are listed herein. Notes "a" through "c" pertain to selected usage of the NO-PASSING ZONE pennant and the worksite NO-PASSING ZONE pennant (orange) by States. All numerical note references adjacent to a particular State are listed below under individual State reference.

No-Passing Zone Pennant Selected Usage Notes

a - Worksite no-passing zone pennant (orange) used.

b - Standard no-passing zone pennant used only at railroad grade crossings or at narrow bridges.

c - The no-passing zone pennant is adopted for usage at selected situations according to the State Manual on Uniform Traffic Control Devices; however, the particular usage is not specifically identified.

Notes on Individual State Practice

Alaska

(1) Uses R4-1 sign, DO NOT PASS, on 2- or 3-lane roads where markings are obscured or impractical in conjunction with R4-2 sign, PASS WITH CARE.

Arizona

(1) Minimum distance between no-passing zones is 400 ft for an 85th percentile speed of 55 mph or greater. In mountainous areas, a minimum of 350 ft between zones may be used when the 85th percentile speed is 50 mph or less.

California

(1) California states that "short-gaps" between successive no-passing zones should be striped continuously; however, they do not specify a minimum length to define "short gap."

(2) The NO PASSING ZONE pennant sign (W14-3) is currently being field evaluated at one site near Sacramento.

(3) California uses (and advocates) a single solid, yellow centerline in mountainous areas for restrictive passing conditions and for a maximum of 500 ft approaching an intersection.

Metric Conversion:
1 ft = 0.305 m
1 mph = 1.609 km/h

Connecticut

(1) Sight distances used:

Posted Speed (mph)	Minimum Passing Sight Distance (ft)
25	400
30	400
35	550
40	650
45	800
50	950

(2) Connecticut marks no-passing zones in advance of rural intersections as above.

(3) Any road narrower than 22-ft travelway is deemed no-passing throughout.

(4) All markings repainted at least annually; high volume roadways are repainted twice each year.

(5) Signing replaced as needed. Approximately 30 percent of existing signs are replaced annually.

Georgia

(1) Uses R 504-1 sign, NO-PASSING WHEN SOLID LINE IS RIGHT OF CENTERLINE, at 10 to 15-mile intervals along highways where no-passing barrier stripes are placed.

Hawaii

(1) Hawaii has adopted California standards for both design and pavement markings.

(2) Hawaii design criteria, the same as California, are assumed to be AASHTO.

Idaho

(1) R4-1 and R4-2 signs are normally used at the beginning and end of a no-passing zone, but are omitted if the no-passing zones are closely spaced.

Metric Conversion:
1 ft = 0.305 m
1 mi = 1.609 km
1 mph = 1.609 km/h

(2) NO-PASSING ZONE pennant is used where driver expectancy could indicate a problem.

Illinois

(1) Illinois uses MUTCD criteria for no-passing zone warrants; however, they enforce on long zone concept.

Kansas

(1) Uses R4-1 sign on all roads with volumes greater than 2000 vehicles a day.
(2) Uses R4-2 sign when the R4-1 sign is used.
(3) Uses W14-3 sign on all roads with volumes greater than 3000 vehicles a day.

Kentucky

(1) In mountain areas where speeds are low and passing opportunities infrequent, the district engineers may connect only those successive zones that are less than 200 ft apart.
(2) The specifications provided by the National MUTCD are used with the exception, PASS ONLY WHEN CENTER LANE IS CLEAR.
(3) The PASS WITH CARE sign should be placed at the end of each no passing zone with few exceptions. In some areas it is safe to pass; however, it may not be desirable to invite passing, i.e., the approach to a school zone or small community. The PASS WITH CARE sign should be omitted in such instances.

Louisiana

(1) Louisiana states use of "long-zone" concept; however, sight distances specified are those of the MUTCD. Louisiana enforcement permits completion of a pass beyond the beginning of the solid barrier line ("clipping").

Metric Conversion:
1 ft = 0.305 m

Maine

(1) Maine correspondence states that they use the long zone concept; however, their sight distance values for establishment of no-passing zones are those specified in the MUTCD.

Mississippi

(1) Uses NO-PASSING sign when markings are obliterated for maintenance purposes.
(2) Uses NO PASSING WHEN SOLID LINE IS RIGHT OF CENTERLINE near the State line. This sign is also used at various locations throughout the State.

Missouri

(1) Missouri states that the long zone concept is used to place the striping and the short zone concept is used for enforcement; however, the minimum sight distances specified for placement use those specified in the MUTCD.
(2) All routes with AADT of 1000 or more shall be marked with no-passing zones.

Montana

(1) MUTCD minimum passing sight distances used; however, Montana specifies a 600-ft minimum length between successive no-passing zones.

Nebraska

(1) R4-1 sign is used where no conventional pavement markings are present.
(2) R4-2 sign is used when R4-1 signs are used.
(3) Uses MUTCD distances but enter the minimum sight distance table with the posted speed limit of the roadway. Also, minimum length between successive no-passing zones is 750 ft.

Metric Conversion:
1 ft = 0.305 m

New Hampshire

(1) Also uses DO NOT PASS WHEN SOLID LINE IS IN YOUR LANE (30 x 36-inch black on white).

New Jersey

(1) Design height lowered to 3 ft.
(2) One line restrictive system used.

New York

(1) New York uses eye/object height of 44 inches.
(2) Minimum length between no-passing zones in urban areas is 200 ft.

North Dakota

(1) North Dakota's policy calls for the installation of barrier stripes only to advise motorists of approaching no-passing zones. Some segments of highways in the State presently are signed for no-passing zones; however, their policy is not to replace these signs.

Oregon

(1) Signs are not normally used to supplement the no-passing stripe except when an engineering investigation indicates that they are needed. The R4-1 sign is used on the right side and sometimes also on the left. The R4-2 sign is also used in these situations.
(2) Oregon uses the MUTCD sight distances except that no-passing are not established for horizontal curves.

Pennsylvania

(1) No-passing zones established on short zone concept but enforcement is dependent on police officer.
(2) Pennsylvania Vehicle Code does not prohibit passing over a no-passing zone marking unless supplemented by signs R4-1, R4-2, NO-PASSING ZONE, NO-PASSING ZONE AHEAD, or END OF NO-PASSING ZONE.

Metric Conversion:
1 in = 25.4 mm
1 ft = 0.305 m

South Carolina

(1) Practically never uses no-passing zone pennant.

Texas

(1) Sign R4-10, DO NOT CROSS SOLID YELLOW LINE IN YOUR LANE TO PASS, is used in advance of the restricted sight distance on roads entering the State and at other highway locations.
(2) Sign R4-9, DO NOT CROSS DOUBLE YELLOW LINE TO PASS, is used.
(3) Texas design passing sight distance criteria are:

Speed Limit (mph)	Passing Sight Distance (ft)
40	1500
50	1800
60	2100
70	2500
80	2700

(4) U.S. and State routes repainted every 8 months; some heavily traveled routes every four months. FM and RR routes repainted every 18-24 months.
(5) Signs are inspected every 6 months, replaced as needed.

Vermont

(1) Vermont correspondence states that they use "long-zone" concept exclusively; however, the sight distances for initiating a no-passing zone are MUTCD values. The termination of the no-passing barrier is based on much longer sight distances than MUTCD specifies.
(2) Minimum length between consecutive no-passing zones is 600 ft for 50 mph design with sight distance of 800 ft and continues until sight distance is 1400 ft. For 60 mph design minimum length between no-passing zones is 800 ft, barrier line starting when sight distance decreases to 1000 ft and continues until sight distance is 1800 ft.

Metric Conversion:
1 ft = 0.305 m
1 mph = 1.609 km/h

Virginia

(1) In mountainous areas, pavement markings are not used; instead, a PASS WITH CAUTION sign is placed at the beginning of the mountainous roadway and repeated at half-mile intervals along the roadway. At the end of the mountainous roadway a sign, DO NOT PASS WHEN SOLID LINE IS ON YOUR SIDE, is placed and barrier stripes are used.

Washington

(1) Signs R4-1 (or W14-3) and R4-2 are used only when resurfacing activities cover the solid line.

Wisconsin

(1) Uses variable minimum length of distance between no-passing zones based on speed:

Speed (mph)	Distance Between Zones (ft)
25-40	528
45-50	660
55 or >	792

(2) The R4-1 sign is used on the State trunk highway system

(3) The R4-2 sign shall be used on the State trunk highway system whenever the R4-1 sign is used.

(4) The W14-3 sign shall be used on State highways and should be used on county highways.

(5) See Note 1, and sight distance criteria below:

Speed Limit (mph)	Sight Distance Requirements	
	Normal Requirements (ft)	Closely Spaced Zones (ft)
25 or 30	525	525
35 or 40	686	686
45 or 50	845	845
55 or 60	1108	1056
65 or 70	1372	1267

Metric Conversion: 1 ft = 0.305 m
1 mph = 1.609 km/h

(6) Signs are replaced on the average of once every six years.

Wyoming

(1) Where the sight distance between successive no-passing zones is less than that specified in the following table, they shall be connected:

Posted Speed Limit (mph)	Minimum Sight Distance (ft)
30	300
40	400
50	500
60	700
70	800

(2) The minimum length of no-passing zone barrier line is as follows:

Posted Speed Limit (mph)	No-Passing Zone (ft)
35	400
40	480
45	560
50	640
55	720
60	800
65	880
70	920

Metric Conversion:
1 ft = 0.305 m
1 mph = 1.609 km/h

(3) R4-2 sign is used for traffic on the downhill grade after a truck climbing lane (estimated 100 sites in Wyoming).

DESIGNATION OF NO-PASSING ZONES

No-Passing Zone Marking Concepts

The data revealed that no States employed the long zone sight distance criteria to establish no-passing zones, although five replies to the FHWA survey stated that the long zone concept was used. It is believed that the statement of use was predicated on enforcement policy, not sight distance criteria, because the State manuals specified sight distance criteria from the national MUTCD (3) but additional information in the survey indicated that pass-completion beyond the start of the solid yellow line was permitted in that State. Three States did not respond to this question in the FHWA survey. The remaining States indicated that no-passing zones were established on the short-zone concept although one State (Vermont) stated that the downstream end of the no-passing zone was established on sight distances greater than those specified in the MUTCD.

The high percentage of usage of the short-zone concept is to be expected since warrants for this concept are specified in the MUTCD. The fact that several States have established for their use minimum passing sight distances that exceed those currently recommended, yet still enforce the passing operations according to short-zone concept, indicates that the safety will be enhanced.

Minimum Passing Zone Length

Most State agencies stated that the minimum allowable spacing between no-passing zones was 400 ft (122 m) as specified in the MUTCD. At least three States have established longer minimum spacing presumably because the 400 ft length (122 m) was considered to be inadequate for safe passing operations. Minimum spacings in Vermont were predicated on speed; 600 ft (183 m) minimum for 50 mph (80.5 km/h) operations, 800 ft (244 m) minimum at 60 mph (96.6 km/h). Statewide nominal minimums of 600 ft (183 m) and 750 ft (229 m) have been established by Montana and Nebraska, respectively. Minimum zone length in Wisconsin is based on speed, and ranges from 528 ft (161 m) to 792 ft (241 m). Wyoming bases minimum zone length on specified sight distances for a given posted speed limit. Two States (Kentucky and Arizona) specify use of minimum passing zones less than 400 ft (122 m) in mountainous areas. Kentucky permits 200 ft (61 m) zones; Arizona permits 350 ft (107 m) if the speed is 50 mph (80.5 km/h) or less. Two States (California and Hawaii) state that "short gaps" between successive no-passing zones should be closed up; however, they do not define "short gap."

Use of Pavement Marking to Designate No-Passing Zones

The use of longitudinal pavement marking (solid yellow barrier stripe) to designate no-passing zones was distributed throughout all States, and except for the occasional use of regulatory signs, represents the primary demarcation technique. In all States, the solid yellow barrier stripe in conjunction with a dashed centerline or another solid yellow stripe (two-way no-passing) designated passing prohibition. The uniformity of application was not complete, however. California, for example, does not mark no-passing zones where continuous rolling terrain produces sequential limited sight distances. In mountainous terrain a single solid yellow centerline is used to denote "restrictive" passing. In Virginia, the practice in certain mountainous areas is not to mark no-passing zones. Instead, the PASS WITH CAUTION sign is placed at the beginning of the mountainous roadway and repeated at half-mile intervals along the roadway. At the end of the mountainous roadway, the barrier no-passing stripe is used again.

With very few exceptions, however, the solid yellow line is used to designate no-passing zones on two-lane highways.

Use of Regulatory Signs at No-Passing Zones

Five States (see reference notes for Table13) use regulatory DO NOT PASS (sign R4-1) at the beginning of no-passing zones as a general statewide practice. Wisconsin uses this sign on State trunk highways; Kansas uses it on roadways with daily traffic volumes in excess of 2000 vehicles per day; Pennsylvania uses it because the State Vehicle Code does not prohibit passing over a no-passing marking unless supplemented by the regulatory sign. At least seventeen States use the R4-1 sign under selected situations including unique terrain or geometric features or where markings are obscured for extended periods of time due to weather or maintenance operations. Table 13 indicates those States that use the R4-1 sign selectively and also the R4-2 PASS WITH CARE sign at the end of the no-passing zone on either a statewide basis or selectively. Several States install regulatory signs with messages similar to DO NOT PASS WHEN SOLID LINE IS IN YOUR LANE (various wordings) at State borders and throughout the highway system, presumably to inform out-of-state drivers that encroachment on the solid yellow line is illegal.

Use of No-Passing Zone Pennant (Sign W14-3)

The NO-PASSING ZONE pennant is used now in more than thirty States with many State agencies adopting its use within the past two years. Recent revisions to the MUTCD in which the suggested usage of the pennant was upgraded from a "may" condition to a "should" condition may have been influential in escalating its usage. There has been increased interest in absolving use of the DO NOT PASS regulatory sign in lieu of the pennant, particularly in some States that have used the regulatory sign for considerable time and have adopted the pennant for general usage.

The pennant represents the primary accepted advance warning traffic control device for no-passing zones. Sixteen States have officially adopted its usage on a statewide basis and eighteen States use it at selected locations. The distribution of this device throughout the nation is shown in Figure 10. Table 13 and corresponding reference notes present details regarding selective usage conditions.

DESIGN CRITERIA

Information regarding criteria used for design purposes was sketchy at best as indicated by Table 13; however, those States providing this information in the FHWA survey indicated unanimously that design was predicated on the current AASHTO policy (21). It is assumed that the other States also use AASHTO criteria for design. Two notable exceptions involved the use of reduced eye/object height. New Jersey indicated that a 3-ft (0.91 m) height is used; New York uses a 44-inch (1.12m) eye and object height.

STATE LAWS AND ORDINANCES

State laws pertaining to road rules and interpretation of traffic control device intent are widely diversified throughout the nation. An excellent comprehensive treatise on State laws on no-passing zones has been prepared by Kearney and Chusid (37). The authors reviewed individual State laws to compare terminology with the provisions of the Uniform Vehicle Code and Model Traffic Ordinance (38). Differences between State laws and applicable sections of the Uniform Vehicle Code were identified for laws regarding driving

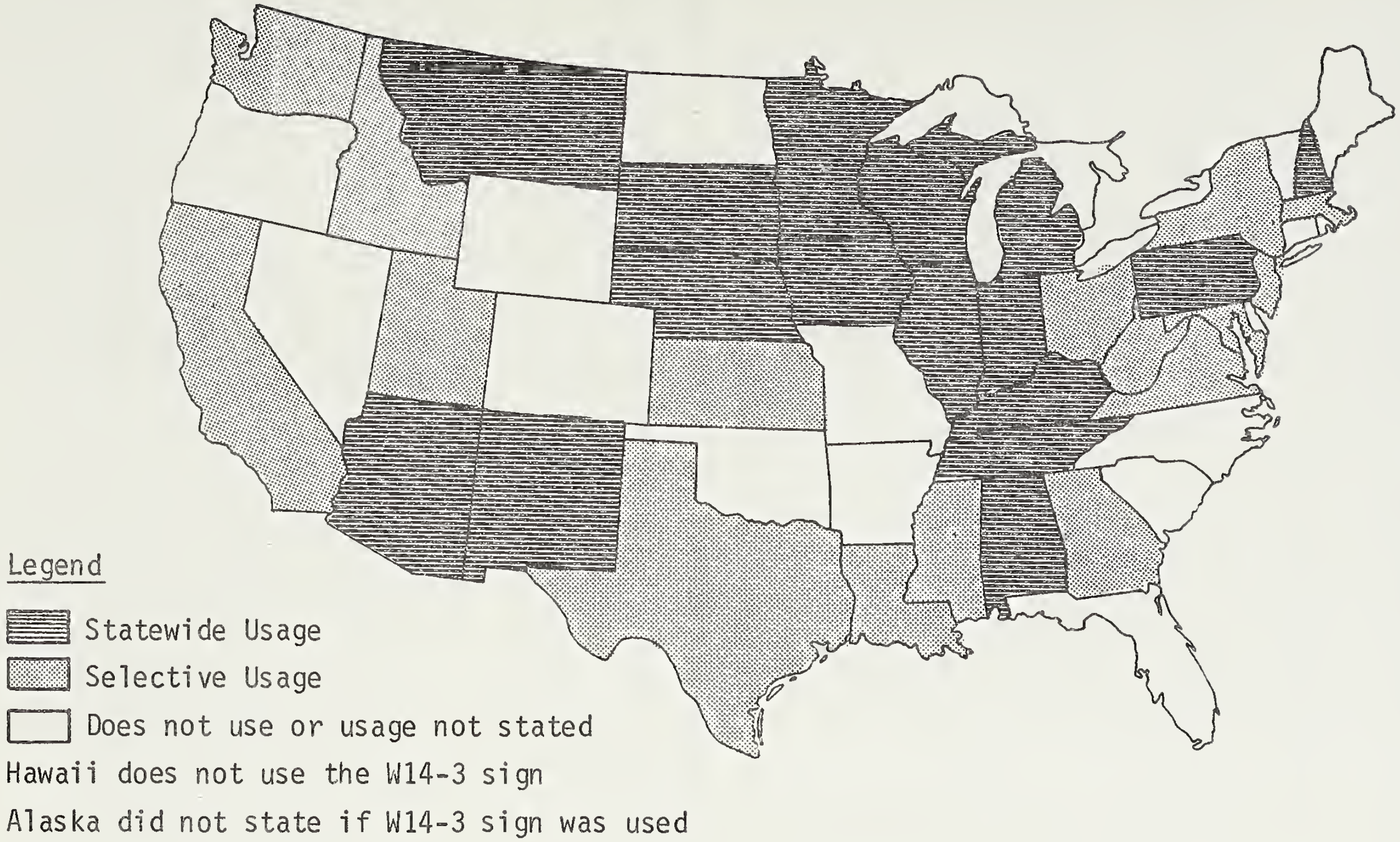

Legend
▤ Statewide Usage
▨ Selective Usage
☐ Does not use or usage not stated
Hawaii does not use the W14-3 sign
Alaska did not state if W14-3 sign was used

FIGURE 10 DISTRIBUTION OF USAGE OF THE NO-PASSING ZONE PENNANT SIGN (W14-3)

on the left side of a highway, passing in unmarked no-passing zones, and passing in marked no-passing zones.

The Kearney and Chusid report represents a significant compendium regarding State laws, and is particularly important to evaluate the legal effect of criteria and warrants for designating passing and no-passing zones and the associated traffic control devices resulting from the research herein.

Kearney and Chusid Observations (37)

The summarizing observations presented by Kearney and Chusid are quoted below. It is interesting to note that many are similar to the concepts and suggested improvements developed in this research.

1. Important driving rules and the meaning of the important traffic control devices must be reasonably uniform. One of the benefits of the recent widespread adoption of right turn on red is that the states are closer together on the meaning of a steady red light.

Rules regulating position on the roadway and passing are so important to safe traffic operation they should be reasonably uniform and simple to understand.

Though there is a good degree of uniformity among laws and court decisions on passing rules and the meaning of no passing zones, laws and decisions allowing completion of a pass after entry into the zone are nonuniform, dangerous and should be changed to conform with the Uniform Vehicle Code unless they can be proven better than the prevailing rule.

2. Research should be undertaken to determine whether a rule allowing a driver to complete a passing maneuver after entry into a no passing zone will improve safety or the movement of traffic. If research does not indicate such benefits, the few states with this rule should be urged to change it as soon as possible.

3. States with the rule allowing completion of a pass after entry into a zone should consider warning their residents about not following that rule when driving in other states. This recommendation makes the dubious assumption that any effort should be undertaken to explain this rule to their residents.

4. The absence of a law banning passing at hazardous locations (such as intersections) would seem to require installing no-passing zones at all such *locations. While this may be desirable outside urban areas, requiring all intersections in cities to be designated as no passing zones is questionable. On the other hand, requiring signs or markings in rural areas, as the laws in a few states do, may be desirable.*

5. Driving on the left, as opposed to driving on the right, should be changed in the Virgin Islands. Allowing driving on the left is particularly dangerous for pedestrians who are accustomed to traffic moving on the right.

ENFORCEMENT PRACTICES

Enforcement personnel from several States have indicated during this research study (19) that enforcement of the no-passing zone represents an important component of their traffic enforcement effort because of the potentially high hazard associated with the passing maneuver. They advocated strongly that it was not desirable to allow motorists to complete a pass in a marked no-passing zone. Additionally, there was strong opinion that development of improved advance visibility characteristics to the current demarcation system would be beneficial to more effective enforcement of the passing maneuver because it would be expected to elicit improved voluntary compliance.

Enforcement personnel questioned during this research also unanimously favored use of the short zone concept and thought the basic longitudinal marking system for no-passing zones should form the core of any improved demarcation system because it is well understood by most drivers.

STATE PRACTICE REGARDING LIABILITY

Several State attorneys have indicated officially or unofficially that one of the most persuasive reasons for adoption of the use of specific criteria, warrants, or traffic control devices is based often on concern for possible vulnerability in litigation should they not be adopted. Several State agencies have indicated that statewide programs for installation of particular traffic control devices at all no-passing zones (rather than only those exhibiting unique features) have been adopted primarily to provide uniformity, and thereby reduce the number of instances in which accident victims may claim that the engineering judgment was erroneous in failing to recognize situations in which no-passing zones were warranted by highway design conditions.

CHAPTER 9

WHAT ARE SOME ALTERNATIVE IMPROVEMENTS FOR TRAFFIC CONTROL DEVICES?

From only the drivers' expressed desire that they be advised of the available safe passing distance ahead, several techniques can be developed to provide this information. It is extremely important to recognize that there is a wide difference between criteria and warrants and driver understanding and interpretation. The issue addressed here concerns those devices that are placed on or alongside the roadway which will provide the necessary information that a passing driver needs to correctly execute the passing maneuver.

Alternative methods can be classified into two categories:

1. Information sources placed at the beginning of a passing zone informing a driver of the length of available safe passing distance ahead, or
2. Information sources placed throughout the passing zone that inform the driver of available remaining safe passing distance until reaching a section of roadway on which passing is prohibited because it is unsafe.

The former exhibits only one apparent positive feature -- it represents "positive" information regarding availability of desired action. It exhibits numerous negative features:

1. It applies to only one discrete location along the highway and would be site specific for every passing zone.
2. Such a method would entail displaying numerical information in terms of feet or kilometers while prior research (6, 8, 9) has shown that drivers are notoriously inept in judging distances.
3. Unless a driver intends to initiate a pass at the specific location, the available passing distance from any location downstream from the point is virtually unknown and the information source can be considered useless.
4. Display of such information would necessitate use of a sign at the beginning of each passing zone. Display of discrete distances with

pavement markings would be extremely expensive, involving considerable manual painting.

Experience in coding such information indicates relatively undesirable interpretation levels. The approach was believed to be nonfeasible and attention was devoted to the second approach.

Several ways can be developed to provide information regarding remaining passing distance, the latter method enumerated above. A rather extensive phase of this research study concerned development and evaluation of alternative methods to improve the safety of passing operations. Numerous alternative approaches were devised, and through engineering evaluation and human factors laboratory studies to determine the practical feasibility and expected driver understanding, those exhibiting greater potential were identified for further study.

Use of conventional signs and markings, modifications to each, and totally innovative traffic control devices were investigated, including verbal messages, graphic (symbolic) messages on signs and in the form of pavement markings. Several concepts were developed for consideration, most of which involved designation of the "critical" position with respect to the downstream end of the passing zone. Conceptual designs were classified within two broad categories: (1) regulatory devices, and (2) advisory (warning) devices. Both categories included the possible use of signs, both verbal and graphic. Marking concepts were developed for the advisory category only; however, several concepts included regulatory signs in conjunction with advisory markings. Descriptions of the many human factors studies conducted on the various approaches are included in Reference 61.

PRELIMINARY WARNING SIGNING CONCEPTS

Three coded left-mounted warning signs were designed for preliminary engineering review as possbile designators of the point at which a passing driver should begin the return maneuver. They included:

1. A small yellow pennant-shaped sign bearing the single black verbal message, AHEAD.
2. A small yellow pennant-shaped sign bearing a black arrow pointing to the right.

3. A small yellow disc bearing a black arrow pointing to the right.

These three devices were developed primarily to display a considered minimum amount of information to see if basic symbology without markings or geometric features to provide additional clues would denote that at this point a driver should either begin to return to the right lane or remain in the right lane if contemplating a passing maneuver. The first two incorporated the believed connotation of the NO PASSING ZONE pennant through shape and color with the additional intended indication of advance warning and intended response. The third was designed to represent a relatively unused color/shape (only circular sign now used is the railroad sign) combination and left-side position to depict a desired response of "move to the right."

The pennant-shaped signs were deleted for further study because it was believed that use of a sign of this shape within the passing zone could seriously detract from the current large pennant sign that is positioned at the start of a no-passing zone. When viewed from a distance, it could be mistaken for a larger sign with the illusion of greater distance. Conflicting meanings of the distinctive shape, color, and position would create misunderstanding and breed disregard for both. Driver understanding of intended meaning was extremely poor, also.

PRELIMINARY REGULATORY SIGNING CONCEPTS

A fourth sign, black on white stating the message, MERGE RIGHT, was proposed as a possible designator of the position of concern. This, too, was deleted from further study after initial studies revealed poor understanding.

PRELIMINARY WARNING MARKINGS CONCEPTS

Two modifications of marking symbology that have been used in other countries were investigated and subsequently deleted for feasible use in this country. One involved the use of slightly curved yellow arrows along the centerline to denote the intent, "to merge to the right lane." The other involved placement of right-pointing arrows in the opposing lane to denote to a passing driver that rightward movement should be initiated. Both concepts exhibit several serious degrading features. The desired response is not properly indicated from only one direction, particularly with the second concept. A driver traveling in the opposing direction views arrows in the reverse direction and the meaning is confusing. Also, of significant importance with the substantial mileage of two-lane roadways in this country, a proposed marking system must be capable of being placed with mechanized striping equipment to be economically feasible. Arrows or other symbolic pavement markings must be placed manually, an undesirable feature. These two concepts (with resulting low driver understanding) were included only to determine potential usefulness in symbolic marking.

Strength of Longitudinal Markings

Practically all signing and marking concepts were studied with and without the conventional solid yellow no-passing stripe visible downstream. The driver responses correctly associating a device with an approaching no-passing zone greatly increased when the solid line was visible. Throughout the human factors studies the presence of the solid yellow barrier stripe to the right of the centerline emerged as a clearly understood designator of no-passing and enhanced the understanding of advance devices. On the basis of this, attention was directed toward development of markings containing longitudinal aspects and position to the right of centerline and signs depicting verbally or graphically the concept of "no-passing ahead." Longitudinal markings can be placed easily with mechanized striping equipment in a variety of patterns. As mentioned before, this was a primary requisite for any proposed marking. Placement of innovative longitudinal markings on either side of the centerline provides the capability to designate intent with respect to direction of travel, and carries with it the connotation of "transition into a no-passing zone," both features being desirable.

CANDIDATE TRAFFIC CONTROL DEVICE CONCEPTS

Knowledge of the location of the end of the passing zone (beginning of next no-passing zone) is the primary traffic control-related information desired by passing drivers. This advance information can be provided in several ways and the techniques discussed here represent the candidate systems producing the best potential feasibility as a result of this research study.

The candidate demarcation systems are classified in seven categories:

1. Longitudinal short-dash (dotted line placed on the right of the roadway centerline throughout the downstream portion of the passing zone for a distance equal to the critical completion distance for a specified operating speed. This system is termed "advance dotted marking" system throughout this report.
2. Vertical mounted designation of the beginning of the no-passing zone to provide advance notification through the longer visibility characteristics of a sign than of merely the currently used solid yellow no-passing barrier stripe.
3. Combination of the advance dotted marking and the vertical marker (sign) at the beginning of the no-passing zone.
4. Advance dotted marking with a right-side mounted warning sign placed at the upstream end of the advance marking to advise drivers that they are approaching the transition zone between safe passing availability and prohibited passing availability.
5. Advance dotted marking with a right-side mounted regulatory sign placed at the upstream end of the advance marking to identify the location beyond which initiation of a passing maneuver is legally prohibited.
6. Combination of the advance dotted marking, right-side mounted warning sign upstream, and left-side mounted warning sign at the beginning of the no-passing zone.
7. Combination of the advance dotted marking, right-side mounted regulatory sign upstream, and left-side mounted warning sign at the beginning of the no-passing zone.

The seven concepts are not listed in order of recommended priority; however, they represent an increasing level of information and progress from warning control only to regulatory control.

Evaluation of Candidate Demarcation Systems

Approximately four hundred subject drivers participated in human factors laboratory studies designed to determine expected understanding of the candidate demarcation systems. (See Reference 61 for details of individual studies.) Subject drivers were shown slides of the candidate demarcation system without instruction as to desired meaning nor reference to the passing maneuver, passing related information, or any reference to the expected correct or incorrect response and asked to describe their interpretation of the demarcation system were they to perceive it on a rural two-lane highway. Results were evaluated against the three correct intended meanings of the demarcation systems:

1. A no-passing zone is located downstream,
2. A driver should not begin a passing maneuver beyond the dotted marking and/or the location of the right-side mounted warning or regulatory sign, but,
3. If a driver is in the act of passing when the demarcation system is reached, the maneuver may be safely completed and the driver should return to the right lane before reaching the prohibitive no-passing zone.

All other answers were considered to be incorrect; however, implications of misinterpretations were given detailed consideration. Since no group of subjects was presented more than one candidate system, there was no learning process between successive systems as the amount of information was increased. Both an item analysis and a pattern analysis were conducted. The former provided a way to compare data across the various conditions to determine if the addition of the signs improved the percentage of correct responses above the base condition of merely the advance dotted marking. Pattern analysis provided frequencies with which subjects under each condition responded correctly only to the intended meaning, and also indicated patterns indicating other interpretations.

With respect to the correct interpretation, "no-passing zone ahead," several findings were observed. Approximately 68 percent of the drivers correctly stated that the dotted lines indicated that they were approaching a no-passing zone. This was increased to about 92 percent with the addition of the right-side warning sign, while addition of only the left-mounted pennant sign increased the understanding about the same (90 percent). It is emphasized that the pennant was essentially as effective as the symbolic warning sign in aiding total understanding. In summary, the advance dotted marking alone was understood by about two-thirds, but the addition of one or both signs was necessary to produce a criteria performance level of at least 85 percent or more (actual level was 90 percent) which would be a desirable goal for understanding.

With respect to the "do not begin passing," 61 percent believed that the dotted marking alone implied that they should not begin passing. The other conditions produced comparable percentages (within sampling error). This is understandable because all signs made reference to no-passing specifically. None of the systems specifically conveys the singular meaning satisfactorily; however, it is believed that drivers must decide this on a site/environment basis, particularly with regard to the passed vehicle speed. As will be discussed later, throughout the studies drivers indicated that, except where passing is determined to be unsafe and illegal, they preferred to be advised (warning informational devices) rather than prohibited (regulatory devices).

With respect to "return before the no-passing zone," subjects understood that the dotted lines alone meant something different than the conventional solid yellow line. Eighty percent recognized that, if they were passing a slower vehicle, they could cross the dotted lines provided they had returned to the right lane before reaching the solid yellow line. The solid yellow line, not the dotted line, designated the point of necessary return. The addition of signs did not appreciably increase the percentage; however, it is strongly believed that a sign at the point of necessary return is a considerably more visible indicator under many environmental conditions. Although the laboratory studies did not investigate visibility, additional evaluation concerning this important characteristic is discussed later in this chapter.

Pattern analysis (ref. 61, Table 20) revealed three predominant patterns with the others being very diversified. Approximately the same percentage of subjects correctly interpreted the three desired meanings (and only the three) under all conditions within a highly consistent percentage range of 38 to 46 percent. The second most common pattern of answers for all conditions was to indicate "no-passing zone ahead" and "return before no-passing zone," but omitting the "do not begin passing" interpretation (range, 51 to 66 percent).

The third most common pattern included selection of the three correct meanings plus stating that the passing vehicle must return before reaching the dotted markings. Although advantageous from solely a safety aspect, this additional interpretation would make the dotted line an upstream extension of the solid yellow line which is not desirable from a roadway capacity aspect.

Several individualized laboratory studies regarding the right-side mounted regulatory sign concept were conducted to determine understanding and preference of message format. In response to a regulatory DO NOT BEGIN PASSING sign, nearly half the subjects elected to abort a passing maneuver that was already begun, although they recognized that the sign stressed "begin." Approximately 14 percent thought it was permissible to pass if the maneuver could be completed before reaching the sign, thus inferring that the sign marked the required completion point. Almost two-thirds of the subjects stated that the sign indicated an upcoming no-passing zone as the reason for placement, but also, two-thirds interpreted that the sign meant that absolutely no passing was to be initiated beyond the sign regardless of the lead vehicle speed. This was stated as a serious deficiency in the technique because drivers prefer to be informed of roadway conditions ahead and decide to pass on the basis of existing conditions, rather than be denied the opportunity to decide.

To further pursue the technique of designating the point by regulatory devices rather than warning, another study was administered to obtain driver preference in wording or sign format. They were instructed to assume that a sign was to be placed alongside a two-lane highway to inform drivers that it is unsafe to start to pass another vehicle because there is a no-passing zone ahead and the driver probably will not be able to complete the pass and return to the right lane before reaching the solid yellow line (no-passing zone). They were shown ten alternative signs (Ref. 61, Study G) and asked to rank the three best and designate the three worst. Eight of the ten candidate signs were regulatory signs, two were warning signs.

The overwhelming preference was the warning sign, NO-PASSING ZONE AHEAD, followed by the warning sign, NO-PASSING ZONE XX FEET AHEAD. Also, the first choice received the second fewest ratings of the "worst three" category. These two received ratings of 60 and 39, respectively, as described in Reference 61. Regulatory messages stating DO NOT BEGIN TO PASS BEYOND HERE, DO NOT START TO PASS, or similar messages, received ratings ranging from 5 to 25. Two symbolic signs received negative ratings of -26 and -27, with by far the most "worst"-category ratings.

In addition to driver understanding, traffic control devices should provide adequate response time -- primarily a function of visibility (target value) and legibility. The candidate systems were compared to determine the relative effectiveness in satisfying these desirable characteristics using as a comparison base the visibility of the conventional no-passing solid barrier stripe.

During the many trips to accident sites, data were compiled regarding the visibility distances to upcoming yellow solid no-passing zone lines. Observations were made of the time elapsed from the point where a solid line was first discernible until reaching the line and the distance was computed from the speedometer reading. In general, all observations were made at approximately 55 mph (88.5 km/h), and included roadways with striping ranging from newly painted to extremely worn conditions and in varied terrain. Roadway grades were estimated. Also, observations were made of visibility distances to new markings on a level test facility under day and night conditions. Day observations resulted in a range of visibility distances from 200 to 400 ft (61 to 122 m); night visibility was about 200 ft (61 m) under high or low beam headlight conditions. Table 14 presents approximate average visibility distances for solid yellow lines beginning on three categories of profile.

TABLE 14 VISIBILITY DISTANCES TO SOLID LINE PAVEMENT MARKINGS

Terrain on Which Line Begins	Range of Visibility Times (sec)	Range of Visibility Distance (ft)	Approximate Average Visibility Distance
Level	3-5	200-400	300
3% Upgrade	10-12	880-1100	1000
Crest of Vertical Curve	2-3	175-260	225

Metric Conversion: 1 ft. = 0.305 m.

The average distance values shown in Table 14 were used to compare the effectiveness of the marking systems.

Relative visibility distances of traffic signs have been examined many times. Hruska (39) measured both visibility and legibility distances for several sign materials. His study, although highly variable, indicated an average legibility distance to black-on-white right-side mounted signs of approximately 600 ft (183 m), ranging from 400 ft (122 m) to slightly over 780 ft (238 m). Observations during the subject study indicate that the left-side mounted no-passing zone pennant exhibits an unobstructed visibility distance of about 1200 ft (366 m) for the 36-inch (91 cm) size. Visibility and legibility distance to this sign are considered to be one and the same because of its unique shape and position and assumed one-time learning characteristic. For effectiveness comparison, therefore, right-side mounted DO NOT PASS signs and the NO-PASSING ZONE pennant sign are assumed to exhibit legibility distances of 600 ft (183 m) and 1200 ft (366 m) respectively.

Table 15 presents relative efficiency ratings of the barrier stripe alone, the barrier stripe in conjunction with a left-mounted pennant or a right-mounted DO NOT PASS regulatory sign, and the advance dotted marking system. The ratings indicate the percent of satisfaction of visibility requirements to identify the beginning of the upcoming no-passing zone from the critical position -- a roadway distance of 2/3 d_2.

The data in Table 15 indicate that even for moderate speeds, the barrier stripe alone is insufficient to accommodate the visual needs for expectancy-conditioning of a motorist on a level roadway (such as approaching a horizontal curve or a hidden dip) or when the stripe begins near the crest of a vertical curve. The appropriate advance notification is received only when the barrier stripe visibility characteristics are substantially enhanced by positive grade, yet the driver is provided other valuable cues in this geometric condition. At operating speeds expected for passing maneuvers on rural highways [55-60 mph (88.5 - 96.5 km/h) minimum] the barrier stripe alone provides only about half the visual requirements on level terrain and less than 40 percent for certain vertical curve situations. The data are based on quality markings viewed in clear dry daylight conditions. For inclement environmental conditions, efficiency ratings would be even lower. The advance dotted marking system provides more than 100 percent visual notification for all speed values as does the left-side mounted pennant in conjunction with the barrier stripe if the pennant is perceived at the critical position. It is believed that the

TABLE 15 EFFICIENCY OF DEMARCATION SYSTEMS IN SATISFYING VISUAL REQUIREMENTS THROUGHOUT THE PASS COMPLETION DISTANCE, 2/3 d_2

85th Percentile Speed (Mph)	Minimum Pass Completion Visual Distance (ft.)	% Efficiency of No-Passing Zone Demarcation System (% of Minimum Visual Requirements)					
		Advance Dotted Marking System	Barrier Stripe Only			Barrier Stripe Plus Right Side Sign	Barrier Stripe Plus Left Side Pennant
			Level	+3%	VC*		
40	325	153.8	92.3	307.7	69.2	184.6	369.2
50	462	129.9	64.9	216.5	48.7	129.9	259.7
55	530	125.0	56.6	188.7	42.5	113.2	226.4
60	598	121.2	50.2	167.2	37.6	100.3	200.7
70	734	115.8	40.9	136.2	30.7	81.7	163.5

Note: (1) Minimum Pass Completion Visual Distance is 2/3 d_2, ft

(2) VC -- Vertical Curve

Metric Conversion: 1 mph = 1.609 km/h

1 ft = 0.305 m

primary advantage of the advance dotted marking system over the pennant is that it is located immediately alongside the vehicle at the position of criticality where the driving task is most critically loaded; hence probably would be more easily recognized than a target downstream. The discrete physical visibility characteristics of the pennant sign are unquestionably superior to the painted line or any existing sign used to designate the beginning of the no-passing zone. Its unique shape and mounting position are considered to be excellent and it undoubtedly provides additional advance notification under wet pavement or nighttime conditions. The only possibly negative feature is that it represents a visual target downstream whereas the advance marking provides a visual target placed precisely at the point of criticality immediately noticeable to the driver.

Restriction of forward visibility due to geometric condition, environmental factors such as roadside foliage or other roadside signs, and leading vehicles (particularly large trucks or closed vans) with minimal window area is a factor that merits concern in evaluating various alternative traffic control devices. Right-side mounted signs offer the least favorable forward visibility characteristics for several reasons. They are blocked by large leading vehicles during the distance the lagging vehicle is trailing and during the overtaking portion until the passing vehicle approaches the critical position. Also, they must be visually separated from other signs and, in the case of the black-on-white regulatory DO NOT PASS sign, the sign must compete in appearance with the common speed limit sign which, on a rural two-lane highway, is a frequently reoccurring sign. The left-side mounted sign offers considerably improved target value to a driver whose attention is, by the subject maneuver, directed primarily to the left lane. This unique position virtually eliminates conflict with other signs and greatly reduces visibility conflict due to leading vehicle blockage. The visibility degradation due to roadside foliage is not, however, alleviated by either side placement and contrast between the yellow sign and foliage background is appreciably less in areas where leaves turn brilliant yellow or brown in the fall season. The advance dotted marking system exhibits desirable characteristics in both aspects -- its visibility characteristics are not degraded by roadside features nor appreciably by vehicle blockage. The advance dotted marking system exhibits one additional positive feature that all systems placed at the beginning of the no-passing zone (downstream) fail to circumvent -- any device placed downstream requires proper driver judgment of distance and speed and concomitant action to execute an intended response. Research has shown that drivers are notoriously inept in accomplishing this as previously stated. The advance dotted marking system completely alleviates the need to judge downstream distance because the downstream reference position is translated upstream physically to designate the critical position immediately adjacent to the vehicle, even under nighttime operating conditions. By merely observing the roadway centerline markings, a driver can immediately decide if sufficient clear distance ahead is offered -- if the dotted marking is not evident before he reaches the critical abreast position he may continue; if it is, he is warned that safe passing distance is rapidly disappearing and he should take appropriate action as dictated by the site conditions.

SUMMARY OF TRAFFIC CONTROL DEVICES FOR SAFE PASSING

Based on the observed driver understanding and known driver capabilities and on the foregoing discussion of visibility characteristics of various signs and markings, the traffic control device concepts indicating the highest feasibility for improving safety in the passing maneuver are summarized below.

1. The system exhibiting the most desirable information needs consists of advance dotted marking throughout the latter portion of the passing zone in conjunction with the no-passing zone pennant placed on the left side of the roadway at the beginning of the no-passing zone. This system provides redundancy in information transfer, a desirable feature of any traffic control device, plus visibility under most environmental conditions -- the sign is desirable when the pavement surface is obliterated by standing water, snow or ice; the marking is desirable in fog or when vehicles or low sign/background contrast restrict visibility. Under proper maintenance, the presence of at least one of the two devices can be reasonably assured, thus reducing the probability of liability due to alleged inadequate demarcation of potentially hazardous sections of roadway.
2. Although the advance marking treatment in conjunction with a right-side mounted NO-PASSING ZONE AHEAD warning sign can be expected to elicit about the same level of understanding as the system above, it is believed that if a sign is to be used in conjunction with the advance marking system, the NO-PASSING ZONE pennant sign offers other positive features that the diamond warning sign does not; primarily longer legibility distance, positive designation of the no-passing zone when reached (enforcement enhancement plus desirable legal liability attribute), and the pennant sign is an existing approved device already being used by many agencies.
3. Positive designation of the location beyond which normal passing should not be initiated is considered definitely desirable; however, this location should be designated by warning devices rather than regulatory devices. Regulatory devices would not permit a driver to initiate and complete a pass around a very slow-moving vehicle if

conditions were such that this could be accomplished before reaching the prohibitive no-passing zone. The passing driver would, however, be forewarned by the marking that he was approaching the no-passing zone and should initiate a pass only under extenuating circumstances, not a situation in which both vehicles were traveling at high speed.

4. The advance dotted marking treatment has not undergone the field trial that the no-passing zone pennant has received; therefore, its substitution for use of the pennant is not valid at this time. It appears, however, from initial evaluations of driver understanding that it offers a highly feasible technique to provide advance warning to drivers that passing opportunity is rapidly decreasing downstream. Its primary attribute is that it removes all driver distance and speed judgmental decision and provides a "go/no-go" type of device--the driver contemplating a passing maneuver receives the needed information from a source immediately adjacent to his/her vehicle at the point of criticality. If the marking system is not present at the point of concern, it represents a "go" condition; if it is present, it represents a "no-go" condition. In addition, the device is visible under all environmental conditions (with the possible exception of snow on the pavement) even at night because it is adjacent to the vehicle and requires no forward visual perception.
5. The current DO NOT PASS black-on-white sign is considered to be a relatively ineffective device and in those States where it is used for primarily legal reasons, consideration should be given to enacting legislation which conveys regulatory meaning to the solid yellow no-passing line, thus alleviating the need for the DO NOT PASS regulatory sign at each no-passing zone.

CHAPTER 10

WHAT ARE SOME ALTERNATIVE IMPROVEMENTS FOR THE DESIGN PROCESS?

As discussed previously, it has been suggested that there is no real need to use two different sets of criteria -- one for design purposes and another for purposes of marking no-passing zones -- if both criteria are supposedly based on safety. The important fact that is so often overlooked is that the design distances suggested (21) are not based on "safety" from the conventional engineering viewpoint. They specify distances which would be desirable for an expected operational condition in that a passing driver could more comfortably execute the total maneuver by being presented necessary downstream roadway sight distance from the point of initiation. This is a highly desirable goal at the design stage because it maximizes passing opportunity and minimizes the "abort" condition if the maneuver is initiated near the upstream portion of the passing zone. At the design stage, the possibility of incorporating grade changes to provide total desirable design passing sight distance is greatly increased. Obviously, provision of total desirable design passing sight distance ($d_1 + d_2 + d_3 + d_4$) at every position along a two-lane highway would provide continuity of passing opportunity, degraded only by presence of opposing vehicles which is a function of traffic volume. Geometric features would create no visual restraints to passing because under this design provision, total sight distance would "unroll" ahead of a moving vehicle as it traveled along the highway. A highway designed and constructed under this provision would not contain any no-passing zones throughout and would not place the passing driver in the abort position at any time because an opposing vehicle could be perceived at the total distance at any point along the highway.

The marking of no-passing zones, conversely, is based on minimum safety criteria, "safety" being defined by the more conventional meaning, "absolute minimum criteria to prevent potential vehicle conflict." The criteria by which passing absolutely must be prohibited, in essence, represent absolute minimum design conditions.

To determine if total distance values alone should be used for design and marking criteria, or if marking criteria alone should be used for design *and* marking purposes, the alternatives must be examined and the probable consequences identified. Advantages and disadvantages are presented for the two extreme condition alternatives by which the design and marking of passing/no-passing zones could be established.

"Total" Distances Used for Design and Marking Purposes

Advantages

1. Conservative (very safe)
2. Would encourage high-quality road profile and operations

Disadvantages

1. High cost regardless of expected volumes
2. Would produce high percentage on no-passing zones on existing roadways
3. Could breed driver disrespect and non-compliance with no-passing zone markings on existing roadways that are restriped on the basis of "total" sight distance.
4. Would be difficult to obtain acceptance by highway agencies
5. Would prohibit many shorter passing zones in which very slow-moving vehicles can be passed
6. Would be difficult to enforce

Minimum Passing Sight Distances Used for Design and Marking Purposes

Advantages

1. Maximizes "passing" zones
2. Minimizes marking costs
3. Provides opportunity to pass very slow-moving vehicles
4. Would produce high level of driver respect for no-passing zone marking

Disadvantages

1. Provides for only *critical* operations
2. Would result in very critical (unsafe) situation when driver misjudges necessary distance
3. Driver must execute $d_1 + 1/3d_2$ in no-passing zones
4. Tends to force driver to complete pass in no-passing zone
5. Could produce legal liability to agency

Even cursory examination of the advantages and disadvantages stated above reveals that use of marking criteria for design purposes would produce design that allows no margin for driver error, *and* use of desirable design criteria for marking no-passing zones would produce unrealistically severe criteria from purely a safety viewpoint. The question, therefore, becomes not "which criteria are safe?" but rather "what is the desirable design goal in terms of expected level of operations, what is the minimum sight distance that _must_ be provided to avoid potential vehicle conflict and what minimum length of roadway constitutes a passing opportunity?"

THE DESIGN PROCESS

The designer currently is afforded limited option in the design stage with virtually no restraints being imposed when he is selecting the roadway profile for providing passing opportunity. In essence, the preliminary profile is established and "design passing sight distance" ($d_1 + d_2 + d_3 + d_4$) is checked for existence. If slight grade changes can be made to provide this sight distance in those cases where available sight distance is only slightly less than desirable, this generally is done. If not, the general practice is to check the design profile to determine where no-passing zones must be marked using MUTCD criteria. The resulting no-passing zone cumulative length is used to determine a ratio (percentage) of roadway now designated as "passing" or "no-passing" and compared to an "acceptable" value. Little regard is given to the operation of the resulting roadway from the aspect of driver usability of the "passing" zones.

Figure 11 illustrates suggested terminology and distance elements combinations that will provide common definition of distances so that the relationship between the design and marking process is presented in a manner that is clear to both the design engineer and the operations engineer. In Figure 11, the four distance components of the AASHTO "Total Passing Sight Distance" are shown in plan view with the notation that "opposing vehicle appears at point B when the passing vehicle reaches point A" (critical position P_c). The AASHTO model operates on the basis that at any point within the distance $d_1 + 1/3d_2$ (pass initiation distance, Figure 11) that a passing driver observes an opposing vehicle and judges the available distance to be inadequate, the passing maneuver will be aborted. This means that "passing sight distance" is not a vital concern throughout this distance because up to reaching the critical position, the passing driver is not committed to the

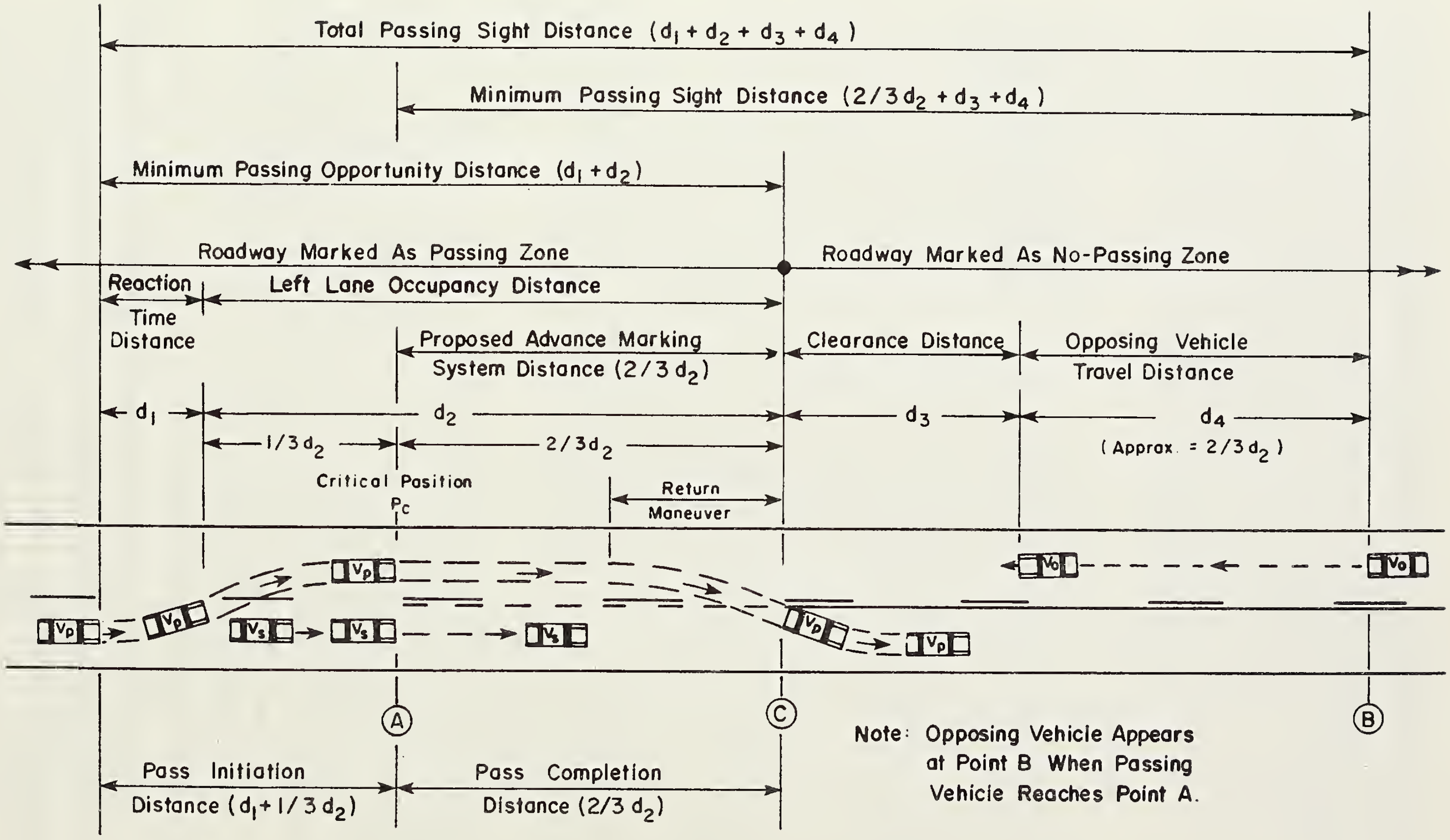

Total Passing Sight Distance ($d_1 + d_2 + d_3 + d_4$)
Minimum Passing Sight Distance ($2/3 d_2 + d_3 + d_4$)
Minimum Passing Opportunity Distance ($d_1 + d_2$)
Roadway Marked As Passing Zone
Roadway Marked As No-Passing Zone
Reaction Time Distance
Left Lane Occupancy Distance
Proposed Advance Marking System Distance ($2/3 d_2$)
Clearance Distance
Opposing Vehicle Travel Distance
d_1
d_2
d_3
d_4
(Approx. = $2/3 d_2$)
$1/3 d_2$
$2/3 d_2$
Critical Position P_c
Return Maneuver
V_p
V_s
V_o
A
C
B
Pass Initiation Distance ($d_1 + 1/3 d_2$)
Pass Completion Distance ($2/3 d_2$)
Note: Opposing Vehicle Appears at Point B When Passing Vehicle Reaches Point A.

FIGURE 11 DISTANCE ELEMENTS AND TERMINOLOGY TO DEFINE PASSING DESIGN AND OPERATIONS

decision to complete the pass and may abort the maneuver with no safety problem. The passing driver, in arriving at the critical position must be able to just see an opposing vehicle and must decide to either abort the maneuver or complete it within a roadway distance of 2/3 d_2 and enjoy a clearance distance of d_3. Therefore, the true minimum passing sight distance, based on appropriate height of eye and object, is the distance from point A to point B, or 2/3 $d_2 + d_3 + d_4$ and, to satisfy the driver's visual needs during the critical portion of the maneuver, this sight distance must be available to a passing driver at point A . This distance is defined in Figure 11 as "minimum passing sight distance," and is applicable for both design and operations. As illustrated in Figure 11, the 2/3 d_2 portion of the minimum sight distance represents the required pass completion distance in traveling from the critical position to the return to the right lane. It is throughout this 2/3 d_2 distance that the advance dotted treatment is proposed. The solid line would begin at point C in Figure 11 and the pennant would be placed on the left side of the roadway at point C, adjacent to the beginning of the solid yellow line.

The roadway distance from point A to point C in Figure 11 actually represents part of the passing zone because it includes the last downstream portion of the passing zone in which a passing maneuver may be completed to return to the right lane before encroaching on the solid no-passing barrier stripe; however, it contains the warning marking system to indicate that passing maneuvers may be completed throughout the zone but should not be initiated.

Passing Opportunity

In determining the percentage of roadway that is considered "passing" or "no-passing," practice has been to sum those lengths of roadway that are marked respectively under MUTCD warrants and compute a ratio of "passing" length to roadway length. The fallacy herein is that a section of roadway not marked as "no-passing" does not necessarily constitute a passing opportunity -- the physical passing maneuver consumes the distance $d_1 + d_2$ as an absolute minimum yet under MUTCD warrants, a 400-ft (122m) length of roadway between two successive marked no-passing zones can be left unmarked which, from a driver's viewpoint, represents a "passing zone." If a passing opportunity is defined as the sum of d_1 and d_2 (reference Figure 11), the lengths of roadway less than this distance yet not marked as no-passing zones do not constitute "passing zones" and should not be included in calculation of percentage of the roadway providing passing opportunity. Under minimum sight distance design the percentage of passing distance is that length of unmarked roadway that exceeds the passing opportunity distance for the particular speed on which the design or marking is predicated.

Designing for Passing Opportunity

It is submitted that, if passing opportunity is to be designed, three factors must be considered:

1. Operating distance for passing under expected conditions,
2. Frequency of passing opportunity along the roadway, and
3. Contingency considerations.

This concept leads to a desirable design and a minimum design philosophy with the contingency considerations applying to a designer's selection of minimum design criteria as summarized below:

1. Distance

    a. Desirable Design -- design for passing operations throughout the roadway length ($d_1 + d_2 + d_3 + d_4$ sight distance).

    b. Minimum Design -- design for critical operations or the "abort" pass condition ($2/3\ d_2 + d_3 + d_4$ sight distance).

    c. No-Passing Zone -- no-passing zones should be established when sight distance is less than that specified for minimum design.

2. Frequency of Passing Opportunity

    When less than desirable design is chosen, the designer must include in the design the provision of passing opportunity on the basis of driver tolerance to prohibition of passing opportunity. Provision of a passing opportunity at approximately two-mile increments is suggested.

3. Contingency

Frequency of passing opportunity may be provided in the form of other geometric features. These "contingency" features must be included in the design process to permit evaluation (cost, expected operations, etc.) of the total design, and include such features as passing lanes, paved shoulders, or possibly information regarding the next available passing opportunity.

Design Speed. The selection of an appropriate design speed for a roadway involves consideration of a great many factors. Key in this consideration is recognition that the driver selects the desired operating speed primarily on the perception of the roadway. Thus, high design speeds invite higher operating speeds. The design should, however, accommodate the speed of a substantial majority of the driving population. In the past when the tendency was to raise legal speed limits on a regular basis and monies were generally available for highway improvements, the use of relatively high design speeds was practical. Present trends suggest that operating speeds as high as 70 mph (113 km/h), with concomitant higher design speeds, probably will not generally be acceptable in the future. The lack of significant funding availability for highway improvements combined with an ever increasing maintenance burden for the existing highway network dictates a somewhat more conservative design speed than has commonly been used in previous years.

To best accommodate the driver, a design speed near that speed which the majority of drivers naturally selects, given a specific set of roadway geometrics, should be used. The 85th percentile speed has long been recognized as the probable upper limit of the "reasonable" driver speed. The 90th percentile speed has been suggested by some as an economic and practical design speed. Review of speed data reveals a difference between the 85th percentile and 90th percentile of only approximately two miles per hour (3.2 km/h). For this reason the 85th percentile speed of vehicles traveling on a roadway of similar design is recommended for both the design and operating speed. Observations of recent speed trends suggest that design speeds of 65 to 70 mph (105 to 113 km/h) are appropriate to accommodate expected operating speeds on rural two lane highways.

DESIGN VALUES

Figure 12 presents graphically, for the expected 85th percentile operating speed, the total passing sight distance for desirable design conditions and the minimum passing sight distances that should be used for design of a highway that would not produce any no-passing zones. Also presented in Figure 12 are the minimum passing opportunity distances applicable for the speed condition. When design constraints dictate provision of sight distance less than the desirable "total sight distance," the greatest practical sight distance should be used, and at no point along the roadway should the sight distance be less than the minimum passing sight distance value shown in Figure 12 and presented in Table 16 for a specified 85th percentile operating speed if the design goal is not to produce any no-passing zones. Where, for practical reasons, the sight distance must be less than the minimum passing sight distance, a no-passing zone shall be established. Provision of sight distance below the minimum passing sight distance can result in excessive delay to traffic and leave the motorist unprepared for the situation ahead. For these reasons, design of passing opportunities on two-lane highways with significant traffic volumes is important.

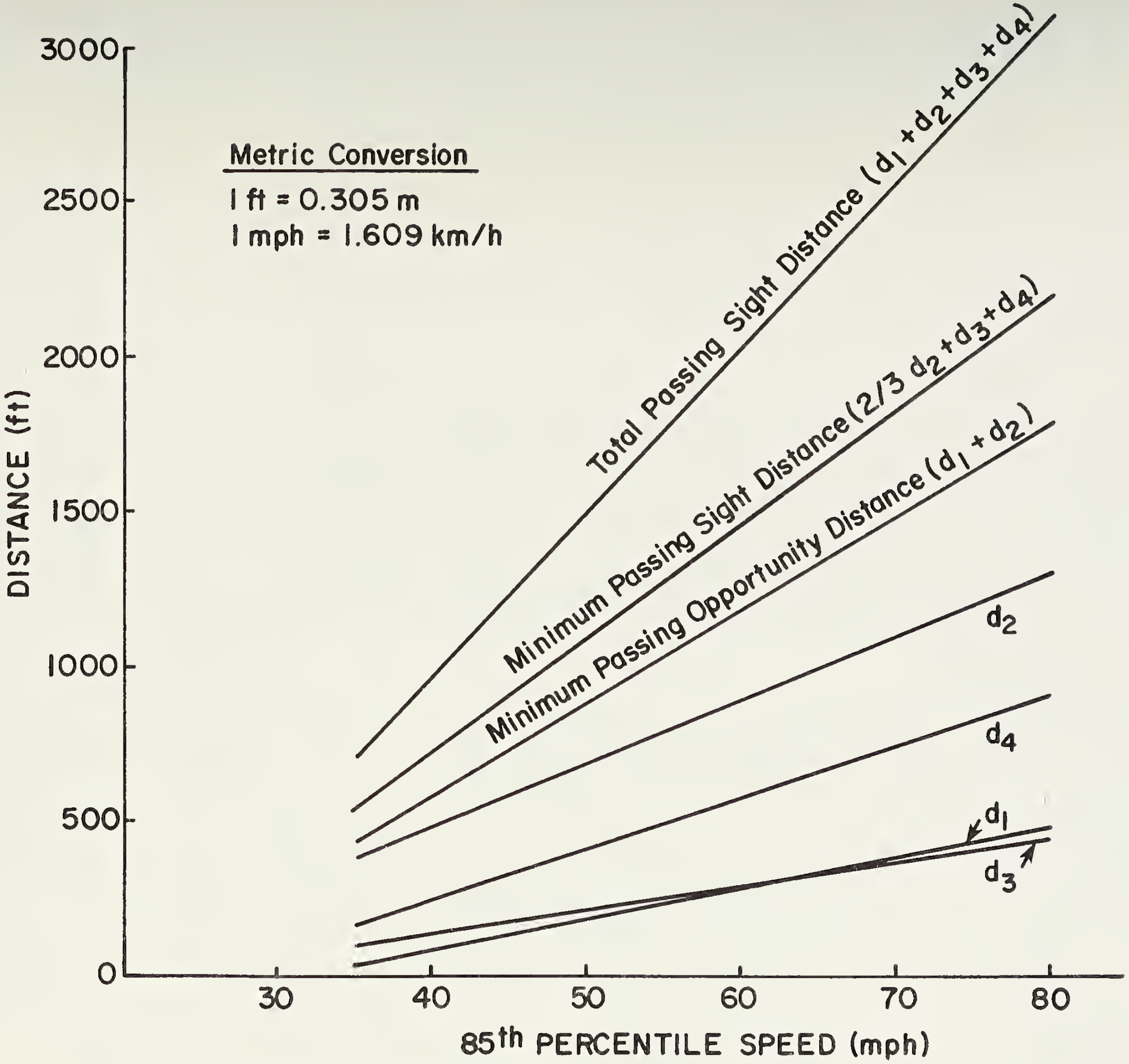


FIGURE 12 PASSING SIGHT DISTANCE FOR DESIGN AND OPERATIONS OF TWO-LANE HIGHWAYS

TABLE 16

PASSING SIGHT DISTANCE FOR DESIGN OR OPERATION OF TWO-LANE HIGHWAYS

85th Percentile Speed (mph)	Total Passing Sight Distance (ft)		Minimum Passing Sight Distance (ft)		Minimum Passing Opportunity Distance (ft)	
	Measured	Rounded for Design	Measured	Rounded for Design	Measured	Rounded for Design
30	427	450	334	350	280	300
35	697	700	521	550	410	400
40	966	1000	708	700	582	600
45	1236	1250	895	900	710	700
50	1505	1500	1082	1100	885	900
55	1775	1775	1269	1275	1035	1050
60	2044	2050	1456	1450	1185	1200
65	2314	2300	1643	1650	1310	1300
70	2583	2600	1831	1850	1486	1500
75	2853	2850	2018	2000	1610	1600
80	3122	3100	2205	2200	1780	1800

Metric Conversion:

1 ft = 0.305 m
1 mph = 1.609 km/h

Note: The measured values represent data from field measurements by Weaver and Glennon (13)

CHAPTER 11

EXPECTED COST BENEFITS FROM PROPOSED NO-PASSING ZONE TREATMENTS

PURPOSE OF THE ECONOMIC ANALYSIS

Traditionally, one of the primary considerations in evaluating a proposed change in concept or practice involves the question, "what benefits can be expected from the change?" Administrators in the highway profession are constantly forced to apportion already-scarce funds to those areas where they believe that the most return will be achieved.

The concept of advance notification (advance warning, driver expectancy, positive guidance, or other terms) is a philosophy generally regarded among traffic engineers as being highly desirable in eliciting proper driver response and; hence, contributes noticeably to highway safety. With respect to the advance warning of a no-passing zone, this philosophy of "need" is evidenced by the rapidly spreading adoption of the no-passing zone pennant, the primary approved traffic control device for this purpose. In many cases, the administrative decision to adopt the concept of advance warning for the no-passing zone appears to have been made, not on detailed cost benefit analysis, but rather on the conviction that driver conditioning to potential hazard is in itself beneficial and the cost of implementing such a system will be offset by improved operations, safety, and the potential for litigation, although these elements have not been quantified precisely.

The concepts developed in this research regarding criteria, application, and design of the traffic control devices by which no-passing zones should be established and designated were critically reviewed by thirty-six traffic engineers in various parts of the country and by an assemblage of members of the National Advisory Committee on Uniform Traffic Control Devices and the Federal Highway Administration in a two-day workshop. In general, the concepts remained unchallenged; the primary concern expresssed was that there existed a definite need to evaluate the benefits that could reasonably be expected from implementation of the proposed treatments for no-passing zones. This would provide a framework for basing a decision to evaluate in actual operation a concept which theoretically appeared sound and reasonable. In response to this rather unanimous expression of opinion, an economic analysis was conducted to predict the expected benefit-cost ratio of application of the advance warning no-passing zone treatments proposed in the research effort.

General Approach

The intent during the economic analysis was to continually employ conservatism; hence, the resulting benefit cost ratio would represent a very conservative estimate of the relative value of the system. In all probability, the benefits would be substantially greater. To assure conservatism, several assumptions were made:

(1) Relatively short sign life was assumed;

(2) Only those drivers that "clip" the no-passing zone were assumed to benefit from the advance treatment;

(3) Interest rate on the high side was assumed.

The approach adopted to compare expected benefits to expected costs on a nationwide basis is outline below:

- Estimate costs of proposed no-passing zone advance treatment nationwide
- Estimate number of no-passing zones nationwide
- Estimate number of passing maneuvers executed annually on two-lane highways nationwide
- Estimate number of passing maneuvers involving "clipping"
- Estimate number of accidents involving sight-restricted passing maneuvers
- Estimate accident reduction due to application of advance treatment
- Estimate number of lives saved
- Estimate reduction in injury and property-damage-only (PDO) accidents
- Estimate dollar savings of advance treatment
- Determine expected benefit-cost ratio

The above tasks were accomplished using a combination of State supplied information, previous research regarding passing operations, accident statistics from several State studies of advance treatment and from national statistics, and field measurements on the passing maneuver by State agencies. National Highway Traffic Safety Administration (NHTSA) cost values were used in computing benefit-cost ratios. The methodology used is discussed in the following sections.

ESTIMATION OF COST ELEMENTS

Expansion Factor for Cost Data

A survey of the States regarding the cost of signing and marking operations was coordinated in 1974 by the Federal Highway Administration and the results were made available for this research study. A summary of the resulting cost data is presented in Table 17. Since costs have escalated appreciably within the past four years, it was necessary to convert the 1974 cost data to equivalent 1978 costs. Three independent scaling approaches were investigated using the construction cost index ratio (41), the consumer price index ratio (42), and the bid-price trend on federal aid highway resurfacing contracts (43).

Construction Cost Index Ratio. Ratioing the index for the first quarter of 1978 to the first quarter of 1974 indicated an apparent 37 percent increase in construction costs during the four-year period as shown (41):

index for first quarter, 1974 = 1961
index for first quarter, 1978 = 2693
Ratio = 2693/1961
= 1.37

Consumer Price Index. Using this measure, the general cost of business increased between 20 and 24 percent in the four year period (42):

1978 CPI = 195 (low estimate)(See Figure 13)
1978 CPI = 202 (high estimate)
1974 CPI = 163
High Ratio = 202/163 = 1.24
Low Ratio = 195/163 = 1.20

Bid Price Trend. The bid price trend for each quarter since 1973 is presented in Table 18. The entry for the first quarter 1978 has been estimated by averaging the first quarter marginal values over the previous quarter for the years 1973 through 1977; the assumption is made that the historical quarterly trend will continue in the future. The bid price index ratio indicates an increase in bid prices of approximately 28 percent (43):

TABLE 17 SUMMARY OF SIGNING AND MARKING COSTS (FHWA-supplied data)

Cost Element	Alabama	Kentucky	Ohio	Wisconsin	Maryland	Pennsylvania	Connecticut
Reg. Signs							
Sign	$4.50/sf	$27.30 ea		$10.00 ea			
Post	$1.00/ft		$10.00 ea				
Labor		$9.50 ea	$36.60 ea				
Total		$36.80 ea	$46.60 ea			$45.00 ea	
Pennant Sign							
Sign	$4.50/sf			$12.00 ea			
Post	$1.00/ft		$10.00 ea				
Labor			$36.60 ea				
Total							$48.00 ea
Painted Lines							
Beads		$10.00 /mi					
Paint		$57.70 /mi					
Labor		$6.00 /mi					
Equipment		$6.00/mi					
Solid Line	$120/mi		$74.40/cont. mi. $60.52/zone mi.	$90.00/mi			$123.72 /mi
Dashed Line	$65/mi	$79.70/mi	$48.13/mi	$90.00/mi	$59.87 /mi	$66.53/mi	$96.20 /mi
Crew Size							
Signs	3		3				
Markings	8			4			8
No. of No-Passing Zones	5000		16,000			12,500	
Pennants in Place			8,800		100		

Legend:
ea - each (unit)
sf - square feet
cont. mi - continuous mile of double yellow line
zone mi - continuous mile of solid/yellow dashed yellow line
ln ft - linear foot

Metric Conversion:
1 ft = 0.305 m
1 sf = 0.0929 m^2
1 mi = 1.609 km

TABLE 17 SUMMARY OF SIGNING AND MARKING COSTS (Continued)

Cost Element	Maine	New Hampshire	New Jersey	Louisiana	Texas	Iowa	California
Reg. Signs							
Sign		$2.25/sf		$9.50 ea			
Post				$12.00 ea			
Labor		$8.00 ea					
Total		$20.00 ea		$21.50 ea			
Pennant Sign							
Sign		$2.25/sf		$14.35 ea		$19.70 ea	
Post				$12.00 ea		$4.25 ea	
Labor		$8.00 ea				$16.00 ea	
Total			$42.00 ea	$26.35 ea		$39.95 ea	
Painted Lines							
Beads					$15.80/mi	$7.52 /mi	$27.26 /mi
Paint					$56.95/mi	$55.33/mi	Incl. in Beads
Labor					$57.25/mi	$16.14 /mi	$11.40 /mi
Equipment					Incl. in Labor	$5.44/mi	$7.10 /mi
Solid Line		$67.80 /mi	$211.00/mi	24¢/ln ft	$130.00 /mi	$53.33/mi	$47.13 /mi
Dashed Line	$123.00/mi			24¢/ln ft			$83.41 /mi
Crew Size							
Signs							
Markings			10-15				4
No. of No-Passing Zones				3000			
Pennants in Place		900		200			

Metric Conversion:
1 ft = 0.305 m
1 sf = 0.0929 m^2
1 mi = 1.609 km

TABLE 17 SUMMARY OF SIGNING AND MARKING COSTS (Continued)

Cost Element	Wyoming	Virginia	Mississippi	Average	Approximate 1978* Equivalents
Reg. Signs					
Sign		$3.40/sf	$22.50 ea	$15.50 ea	$20.00 ea
Post		$0.25/ft	$11-16 ea	$9.70 ea	$12.00 ea
Labor		$5.10/sf		$19.90 ea	$26.00 ea
Total	$96.00 ea	$45.00 ea	$36.50 ea	** $43.42 ea	*** $56.40 ea
Pennant Sign					
Sign				$16.70 ea	$21.70 ea
Post		$0.05/ft	$11-16 ea	$9.21 ea	$12.00 ea
Labor				$20.00 ea	$26.00 ea
Total				** $39.00 ea	*** $50.90 ea
Painted Lines					
Beads				$11.10 /mi	$126.00/mi
Paint				$57.00 /mi	
Labor				$22.70 /mi	
Equipment				$6.18 /mi	
Solid Line	$80/mi incl. paint & beads	2.5¢/ft		$104/mi	$135/mi
Dashed Line		2.5¢/ft		$79/mi	$103/mi
Crew Size					
Signs				3	3
Markings				7	7
No. of No-Passing Zones				9125	X 50 States≐456,250 NP Zones
Pennants in Place					

* Expansion Factor 1.3 Applied to average reported cost

** Average "Total" is the numerical average of the total cost reported by State (not necessarily the sum of the individual costs)

*** Totals represent expanded average of all "total" costs reported by States

Metric Conversion:
1 ft = 0.305 m
1 sf = 0.0929 m^2
1 mi = 1.609 km

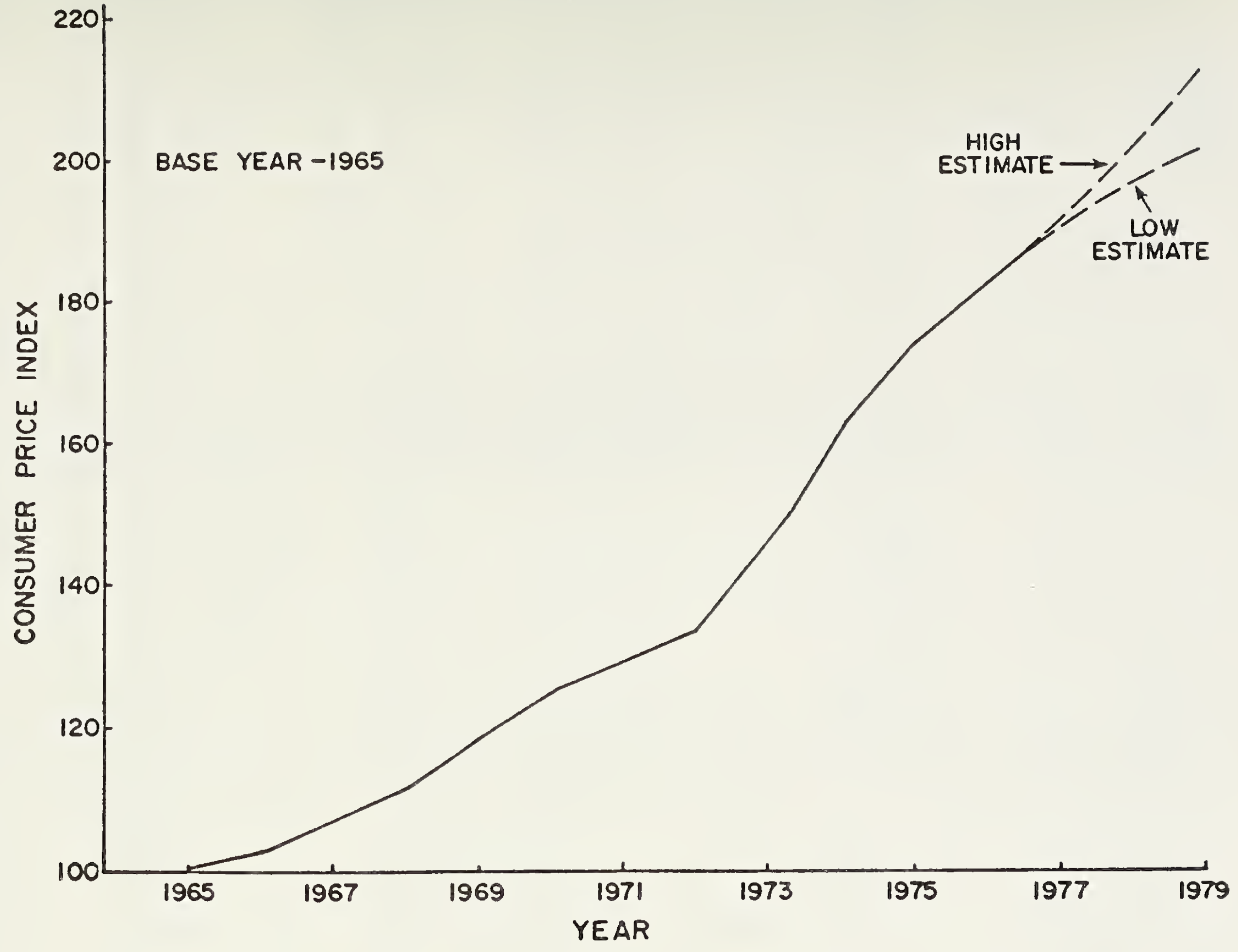


FIGURE 13 CONSUMER PRICE INDEX (42)

TABLE 18
SURFACING COST INDEX - 1973-1978 (43)

Year	Quarter	Combined Index	Marginal Value
1973	1	150.3	+ 8.4
	2	148.2	- 2.1
	3	154.7	+ 6.5
	4	167.7	+13.0
1974	1	Base 194.6	+26.4
	2	216.8	+22.0
	3	212.4	- 4.4
	4	219.7	+ 7.3
1975	1	219.1	- 0.6
	2	203.2	-15.9
	3	215.5	+12.3
	4	227.7	+12.2
1976	1	212.3	-15.4
	2	205.5	- 6.8
	3	219.4	+13.9
	4	217.4	- 2.3
1977	1	212.6	- 4.8
	2	224.1	+11.5
	3	231.8	+ 7.7
	4	247.1	+15.3
1978	1	249.9*	

* Extrapolated value

Bid Price Index, 1974 = 194.6
Bid Price Index, 1978 = 249.9 (Figure 13)
Ratio = 249.9/194.6 = 1.28

Selection of Expansion Factor. The three independent approaches indicate a range of from 25 to 35 percent increase in costs from 1974 to 1978. A midpoint value of 30 percent was selected for use in the economic analysis. The 1978 costs in Table 17 were estimated using a 1.30 factor applied to the 1974 average cost of items applicable.

Estimation of Proposed No-Passing Zone Treatment Costs

The cost of the proposed no-passing zone treatment is based on the following information:

(1) Sign life of 7 years,
(2) Marking life of 8 months,
(3) Interest rate of 10 percent,
(4) Marking cost of 2.5¢ per foot (8.2¢ per meter),
(5) Advance treatment of 550 ft (55 mph operation) (168 m, 88.5 km/h),
(6) Pennant sign cost $51 each (average installed, 1978 equivalent cost).

Marking Cost. Based on 550 feet of treatment at 15 linear feet per 40-ft pattern, 2.5 cents per foot, and a repainting schedule of each 8-month period, the costs are so shown:

$$\text{Annual Cost} = 550\text{ ft.} \times \frac{15\text{-lf}}{40\text{-ft. pattern}} \times \$0.025/\text{ft.} \times 12/8 = \$7.69$$

The cost of the advance dotted line actually will be less than this value because it would be placed at the same time the centerline was placed; however, this conservative cost value is used for analysis purposes.

Sign Cost. The expected sign cost, using the $51 pennant cost and a capital recovery factor of 0.205 (10%, 7 years) is:

$$\begin{aligned}\text{Annual Sign Cost} &= \$51.00\ (0.205)\\ &= \$10.46\end{aligned}$$

Total Cost. The expected total cost per no-passing zone is $18.15, the sum of the marking and signing costs identified above.

ESTIMATION OF THE NUMBER OF NO-PASSING ZONES

The precise number of no-passing zones nationwide is not documented. In fact, this information was received from relatively few States in the FHWA survey. Therefore, it was necessary to estimate the number using several sources of available data. Byington (44) reported that approximately two no-passing zones exist per mile on two-lane highways in Virginia. Based on a national estimated total two-lane highway mileage, this translates to approximately 1,116,408 no-passing zones nationwide. The topography in Virginia suggests that this estimate is probably high.

Table 19 presents a summary of individual State estimates of the no-passing zones based on extrapolation from observation along a 100-mile length (160.9km) of two-lane roadway. The data were compiled from observations made in twenty-eight States. The number of no-passing zones in the remaining States was estimated by matching similar State size, terrain and roadway mileage for which estimates were available. From this process, the nationwide number of no-passing zones was 835,000. The limited data from the FHWA survey are presented in Table 20.

TABLE 20

NUMBER OF NO-PASSING ZONES REPORTED BY FOUR STATES

Alabama		5,000
Ohio		16,000
Pennsylvania		12,500
Louisiana		3,000
	Total:	36,500
	Average:	9,125

Based on an average of 9,125 no-passing zones per State a total national estimate would be 456,250. This figure represents the least probable value that could reasonably be expected.

TABLE 19

ESTIMATE OF THE NUMBER OF NO-PASSING ZONES BY STATE

State	Approximate Number of No-Passing Zones	State	Approximate Number of No-Passing Zones
Alabama	38,000	Montana	9,000
Alaska	5,000*	Nebraska	12,000*
Arizona	8,000	Nevada	6,900
Arkansas	40,000*	New Hampshire	7,600
California	20,000*	New Jersey	800
Colorado	11,200	New Mexico	13,800
Connecticut	7,000*	New York	16,000
Delaware	6,600	North Carolina	45,000*
Florida	10,600	North Dakota	6,000*
Georgia	28,800	Ohio	16,000*
Hawaii	1,900	Oklahoma	12,000*
Idaho	5,000*	Oregon	10,000*
Illinois	15,000	Pennsylvania	22,200
Indiana	12,000*	Rhode Island	500
Iowa	15,000	South Carolina	47,000
Kansas	12,000*	South Dakota	6,000*
Kentucky	18,000*	Tennessee	18,800
Louisiana	30,000	Texas	95,000
Maine	4,000*	Utah	4,500
Maryland	16,800	Vermont	4,400
Massachusetts	5,000	Virginia	43,500
Michigan	18,000*	Washington	12,000*
Minnesota	20,000*	West Virginia	30,000*
Mississippi	13,100	Wisconsin	16,000*
Missouri	16,000*	Wyoming	3,000
		TOTAL	835,000

* Estimated values determined by comparison with States of similar size and topography

The three basic estimating procedures produce a wide range of estimates, the low estimate being about 500,000 no-passing zones nationally with the upper value appearing to be about 1,100,000. The average of the two extremes is about 800,000, which compares favorably with the detailed estimate. For this reason the 835,000 no-passing zones determined in the detailed analysis (Table 19) was selected as the expected value and used throughout the economic analysis.

ESTIMATION OF THE BENEFITS OF THE ADVANCE NO-PASSING ZONE TREATMENT

Estimation of the Annual Number of Passing Maneuvers on Two-Lane Highways

The 1974 Highway Statistics (45) present a summary of the mileage of two-lane roadway [20 and 26 ft. wide (6.1 and 7.4 m)] in each of several ADT classifications. These data are presented in Table 21.* The Highway Capacity Manual (46) presents a relationship between the peak loadings and the frequency with which the loadings occur on the two-lane highway system. The data in Table 22 were generated by averaging extremes within each range.

TABLE 22

RELATIONSHIP OF PEAK DEMAND AND FREQUENCY OF OCCURRENCE ON THE TWO-LANE HIGHWAY SYSTEM

Average Percent of ADT	Hours Occurred
15.7	0- 30
12.3	31- 200
10.2	201- 400
7.1	401- 800
3.6	801-8760

By multiplying the average percent of the ADT presented in Table 22 by the midpoint value of the ADT ranges presented in Table 21, expected hourly volumes for each ADT range can be obtained. Table 23 presents the results of this process. From Table 23, the time within each hourly volume can be determined.

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*See following page.

TABLE 21
NATIONAL MILEAGE OF TWO-LANE HIGHWAY BY ADT (45)

ADT Range	Mileage Within ADT Range	Total Vehicle Mileage
0 - 400	57,929	11.6×10^6
400 - 1000	74,745	52.3×10^6
1000 - 2000	71,686	107.5×10^6
2000 - 3000	38,945	97.4×10^6
3000 - 4000	21,163	74.1×10^6
4000 - 5000	11,592	52.2×10^6
5000 - 10000	14,044	105.3×10^6
10000 - 15000	1,678	21.1×10^6
15000 - 20000	261	4.6×10^6
20000 - 30000	51	1.3×10^6
30000 - 40000	3	0.1×10^6
Over 40000	5	0.2×10^6
	TOTAL	527.7×10^6 vehicle miles per day

Metric Conversion:
1 mile = 1.609 km

TABLE 23

EXPECTED HOURLY VOLUMES FOR EACH ADT GROUP

ADT Range	Mid-Point Value	Mileage in ADT Range	HOURLY VOLUMES				
			Percent of ADT				
			15.7	12.3	10.1	7.1	3.6
			Hours 30	170	200	400	7960
0- 400	200	57,929	31	25	20	14	7
400- 1000	700	74,745	110	86	71	50	25
1000- 2000	1500	71,686	236	185	152	107	54
2000- 3000	2500	38,945	393	308	253	178	90
3000- 4000	3500	21,163	550	431	354	249	126
4000- 5000	4500	11,592	706	554	455	320	162
5000-10000	7500	14,044	1178	923	757	533	270
10000-15000	12500	1,678	1963	1537	1263	890	450
15000-20000	17500	261	2750	2125	1768	1242	630
20000-30000	25000	51	3925	3075	2525	1775	900
30000-40000	35000	3	5495	4305	3535	2485	1260
40000 plus	40000	5	6280	4920	4040	2840	1440

Metric Conversion:
1 mile = 1.609 km

Multiplying the number of hours represented by the peak period percentage by the mileage of roadway in each ADT classification, hourly-miles at each ADT level can be generated.

Using the curve presented in Figure 14, the average number of passing maneuvers for each ADT group can be determined. The product of the hourly-miles at each ADT level and the average number of passing maneuvers for that group summed over all ADT groups produces an estimate of the total number of passing maneuvers during one year (Table 24).

Estimation of the Number of Passing Maneuvers Performed With No On-Coming Vehicle in Sight

Normann (10) determined that 59.7 percent of all passing maneuvers were performed in the absence of an opposing vehicle. The product of this percentage and the total number of passing maneuvers performed (Table 24) provides an estimate of the number of passing maneuvers executed when available sight was the limiting factor (P_{SR}).

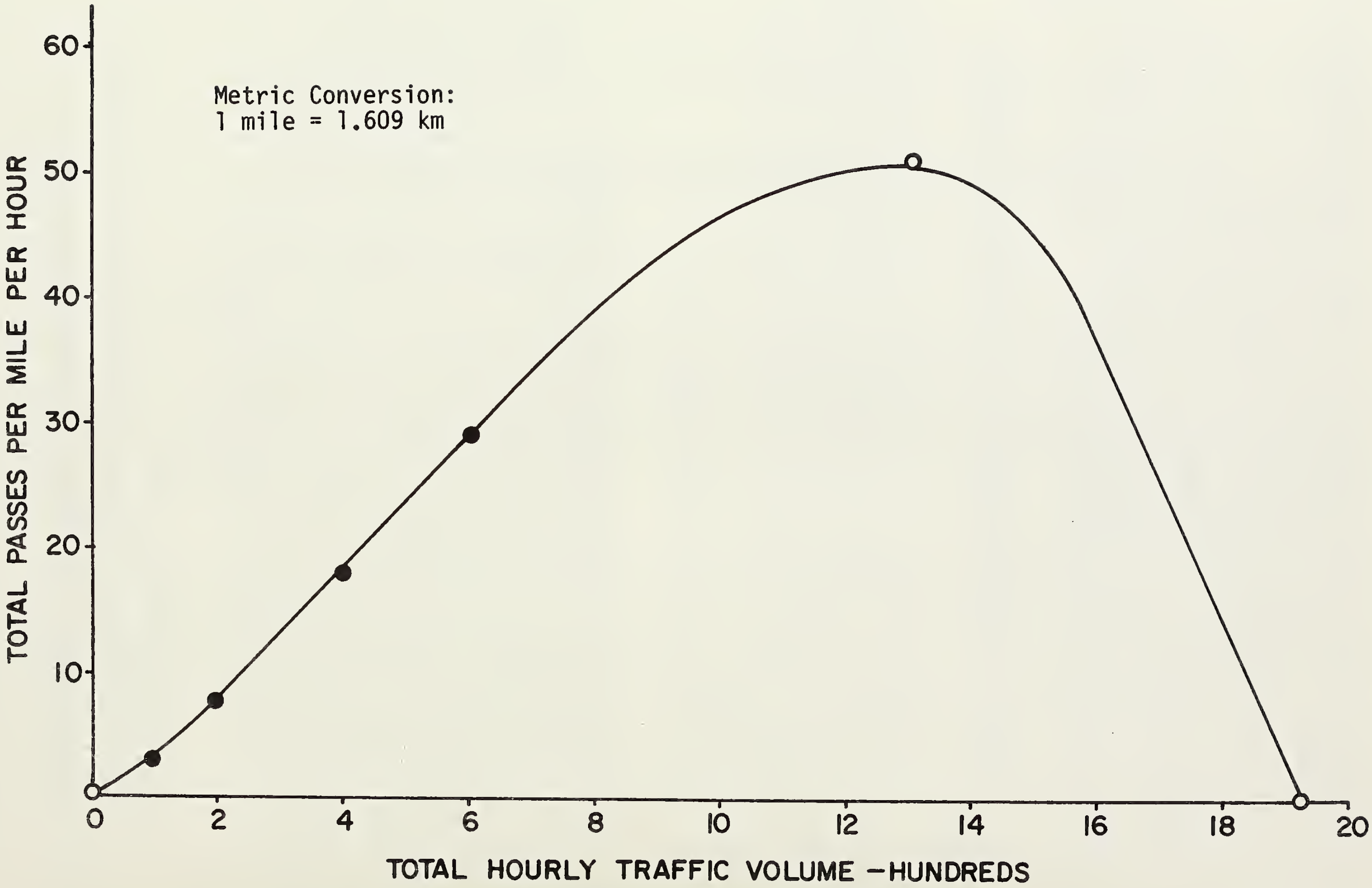
$$P_{SR} = 0.597 \times 7451.2 \times 10^6 = 4448 \times 10^6$$

Estimation of the Number of Passing Maneuvers Involving "Clipping"

A study by the Michigan Highway Department in 1966 (47) revealed that "clipping" occurred in 14 to 17 percent of the total number of passing maneuvers on a two-lane highway. The human factors studies in the subject research indicated that about 18 percent of the drivers "clip" the no-passing zone at the end of their maneuver quite frequently (Ref. 61, Figure 1). Assuming that 15 percent of passing drivers would clip in the normal passing situation and in the absence of opposing traffic, the total number of passing maneuvers for which the advance treatment could be expected to benefit can be calculated as shown below:

$$P_{CLIP} = 0.15 \times 4448 \times 10^6 = 667 \times 10^6$$

This number represents the annual number of passing maneuvers on two-lane highways that terminate beyond the start of the no-passing zone.



Metric Conversion:
1 mile = 1.609 km

FIGURE 14 RELATIONSHIP BETWEEN PASSING RATE AND TRAFFIC VOLUME (50, 54)

TABLE 24

ESTIMATE OF THE NUMBER OF PASSES FOR EACH HOURLY VOLUME GROUP

Hourly Volume	Hourly Miles at Indicated Volume	Average Number of Passes Per Miles Per Hour	Estimated Number of Passes Per Year
0- 100	2041.0×10^6	1.5	3061.5×10^6
100- 200	333.7×10^6	5.4	1802.0×10^6
200- 300	130.2×10^6	10.5	1367.1×10^6
300- 400	16.7×10^6	16.0	267.2×10^6
400- 500	19.3×10^6	21.2	409.2×10^6
500- 600	5.4×10^6	26.6	143.6×10^6
600- 700	2.1×10^6	32.1	67.4×10^6
700- 800	3.2×10^6	37.5	120.0×10^6
800- 900	1.1×10^6	41.5	45.7×10^6
900-1000	2.4×10^6	45.0	108.0×10^6
1000-1100	0.0×10^6	47.6	0.0×10^6
1100-1200	0.4×10^6	49.4	19.8×10^6
1200-1300	0.5×10^6	50.3	25.2×10^6
1300-1400	0.0×10^6	50.0	0.0×10^6
1400-1500	0.0×10^6	47.6	0.0×10^6
1500-1600	0.3×10^6	41.6	12.5×10^6
1600-1700	0.0×10^6	30.4	0.0×10^6
1700-1800	0.1×10^6	19.5	2.0×10^6
1800-1900	0.0×10^6	8.2	0.0×10^6
		TOTAL	7451.2×10^6

Metric Conversion: 1 mile = 1.609 km

Estimation of Passing Accidents Involving an Illegal Sight-Restricted Passing Maneuver

Data from the Federal Aid Fatal and Injury Accident Rate Study in 1974 (48) reveal that the fatality and injury accident rates for rural non-Interstate Federal Aid Highways were 3.2 and 59.5, respectively per 100 million vehicle-miles. The number of fatalities and injury accidents eliminated can be estimated by multiplying these rates and the annual vehicle miles. From Table 21, the total vehicle miles of travel per day is 527.7×10^6 which represents 192,600 million vehicle-miles annually. (1 mile = 1.609 km)

Therefore;

$$\text{Fatal Accidents} = 3.2 \times 192{,}600 \times 10^{-2} = 6{,}163$$

$$\text{Injury Accidents} = 59.5 \times 192{,}600 \times 10^{-2} = 114{,}597$$

The 1974 edition of Accident Facts (49) indicates that 19,300 fatal accidents, 230,000 injury accidents, and 2,240,000 property-damage-only accidents (PDO) occurred on the rural state road system in 1973. This resulted in 420,000 injuries and 23,300 fatalities. Expanding the injury accident figures by the ratio of PDO accidents to injury accidents, an estimate of the number of PDO accidents on Federal-Aid Highways can be obtained:

$$\text{PDO Accidents} = \frac{2{,}240{,}000}{230{,}000} \times 114{,}597 = 1{,}116{,}000$$

The distribution of two-lane highway accident severity therefore becomes:

Fatal Accidents:	6,163
Injury Accidents:	114,597
PDO Accidents:	1,116,000
Total:	1,236,760

A study conducted by the Franklin Institute Research Laboratories (50) concluded that approximately 10 percent of the accidents on the two-lane system were passing-related. Therefore, an estimate of the total number of passing-related accidents is 10 percent of the values above, or:

$$A_{\text{PASSING}} = 0.10(1{,}236{,}760) = 123{,}676$$

The passing-related accidents in which sight distance is the visual restriction can be estimated by the product of the total passing-related accidents (A_{PASSING}) and the ratio of the number of passing maneuvers involving clipping (P_{CLIP}) to the total number of passing maneuvers (Table 24):

$$A_{CLIP} = 123{,}676 \times \frac{667\text{x}10^6}{7451\text{x}10^6} = 11{,}071$$

Thus, an estimated 11,071 passing-related accidents occur annually in which the maneuver was initiated in the passing zone and involved an illegal sight-restricted completion.

Estimation of the Number of Accidents that Would be Eliminated by Application of Advance Treatment

The human factors studies indicated that approximately 74 percent of the subject drivers occasionally "clip" during the passing maneuver (Ref. 61, Figure 1). Further, about 69 percent understood the meaning of the advance treatment without prior education. Thus, approximately 51 percent of the drivers could be expected to respond correctly to the advance treatment system. The number of clipping accidents that could expected to be eliminated through extensive use of the proposed advance no-passing zone treatment can be estimated as follows:

$$A_{ELIM_{low}} = 0.51 \times 11{,}071 = 5{,}646 \text{ accidents per year}$$

With minimal education, 94 percent correct understanding was demonstrated (61). Therefore, the long-term effects could be estimated as:

$$A_{ELIM_{high}} = 0.94(0.74)(11{,}071) = 7{,}700 \text{ accidents per year}$$

Estimation of the Number of Lives Saved

The accident investigation phase of this research (Reference 60) indicated that approximately 3.5 percent of all passing accidents involve a fatality. Applying this factor to the low and high estimates of accident reduction above produces an estimate of the number of fatalities that can be expected to be eliminated annually by application of the advance treatment:

$$\text{Fatalities Eliminated}_{low} = 0.035(5646) = 198$$

$$\text{Fatalities Eliminated}_{high} = 0.035(7700) = 270$$

Estimation of the Number of PDO and Injury Accidents Eliminated by Application of the Advance Treatment

Property-damage-only and injury accidents represent the difference between total accidents eliminated and the number of fatal accidents. Kemper, et. al. (51) stated that 42 percent of the non-fatal passing accidents result in injury. The number of PDO and injury accidents eliminated can be estimated by applying this factor to the low and high estimates above:

$$\text{Injury Accidents Eliminated}_{\text{low}} = 0.42(5646-198) = 2288$$
$$\text{Injury Accidents Eliminated}_{\text{high}} = 0.42(7700-270) = 3121$$
$$\text{PDO Accidents Eliminated}_{\text{low}} = 0.58(5646-198) = 3160$$
$$\text{PDO Accidents Eliminated}_{\text{high}} = 0.58(7700-270) = 4309$$

Estimation of the Dollar Savings by Application of the Advance Treatment of No-Passing Zones

The National Highway Traffic Safety Administration (52) estimates the total societal costs of automobile accidents as:

Fatality	$287,175
Injury	$ 8,085
PDO	$ 520

Using these values, the expected annual savings in the United States by use of the advanced treatment of no-passing zones can be estimated:

Low Estimate

Annual Savings = 198(287,175) + 2288(8,085) + 3160(520) = $77.0 million

High Estimate

Annual Savings = 270(287,175) + 3121(8,085) + 4309(520) = $105 million

The annual dollar saving per no-passing zone in the nation is this saving divided by the total number of zones. As previously indicated, the low estimate of the number of no-passing zones in the United States is about 500,000; the high estimate is about 1,100,000; and the most probable estimate is about 835,000. The dollar annual savings per zone can be determined and are presented in Table 25.

TABLE 25

EXPECTED ANNUAL SAVINGS PER NO-PASSING ZONE BY APPLICATION OF PROPOSED ADVANCE TREATMENT

Low Estimation: $\frac{\$77,000,000}{1,100.000} = \$70$ per zone

High Estimation: $\frac{\$105,000,000}{500,000} = \$210$ per zone

Most Probable Estimation: $\frac{\$91,850,000}{835,000} = \$110$ per zone

BENEFIT/COST COMPARISON

The annual cost of the advance treatment concept (marking and pennant sign) computed previously using average costs (Table 17) was determined to be $18.15 per zone per year. Using extreme values of marking and sign costs from Table 17, the low and high estimated annual costs per zone are $10.71 and $22.11, respectively. The expected Benefit/Cost ratio for the systems, determined as the ratio of the savings to the annual cost of treatment, is presented in Table 26 for the "low," "high," and "most probable" estimates.

TABLE 26

BENEFIT/COST RATIO OF ADVANCE NO-PASSING ZONE TREATMENT

Low	$\frac{\$\ 70.00}{\$\ 22.11}$	=	3.2
High	$\frac{\$210.00}{\$\ 10.71}$	=	19.6
Most Probable	$\frac{\$110.00}{\$\ 18.15}$	=	6.1

SUMMARY OF FINDINGS

In the economic analysis presented above, every attempt has been made to insure that the results would be conservative, except for the choice of cost for accidents. The NHTSA values are so well established that their use seemed appropriate without further discussion. The reader should note that even if these values were scaled down by a factor of three, the proposed advance treatment system would still be cost-effective.

Therefore, it is concluded that the proposed advanced treatment system (sign and markings) has a high probability of being cost-effective if used nationwide. Certainly, the findings indicate that use of such a system in areas of high passing-accident frequency is warranted and a thorough field trial of the concept to measure the benefits directly is justified.

CHAPTER 12

RESEARCH RESULTS

The concepts developed in this research effort are based on the findings from measured vehicle performance under real-world conditions, from driver understanding and stated preferences of specific traffic control devices, and from analyses of vehicle performance capabilities. The recommended techniques are tempered with respect to practical application using existing technology in equipment and traffic operations. They represent an engineering concept by which the existing process of designing and marking two-lane highways may be accomplished on the same rationale employing common terminology. The feasibility of the concept of advance treatment for no-passing zones developed herein appears highly favorable with respect to driver understanding and to satisfying the driver informational needs during the decision process and execution of a safe passing maneuver.

Presented in this chapter is a summary of the sight distance values resulting from the research used in designing two-lane rural highways for safe passing operations and establishing and demarking no-passing zones when passing must be prohibited.

SUMMARY OF TERMINOLOGY

To avoid ambiguity in definitive terminology relating to the passing maneuver, the distance elements comprising the maneuver as used in this report are defined herein and illustrated in Figure 15.

Critical Position (P_c)

The critical position of the passing maneuver is defined as the point in time and space where the passing vehicle in the left lane is adjacent to the vehicle in the right lane being passed. From measured vehicle performance (10, 12, 13) this relative position of vehicles occurs at the one-third point of the left lane travel distance, d_2. At this point in the maneuver, the passing driver must make the decision to complete or abort the pass.

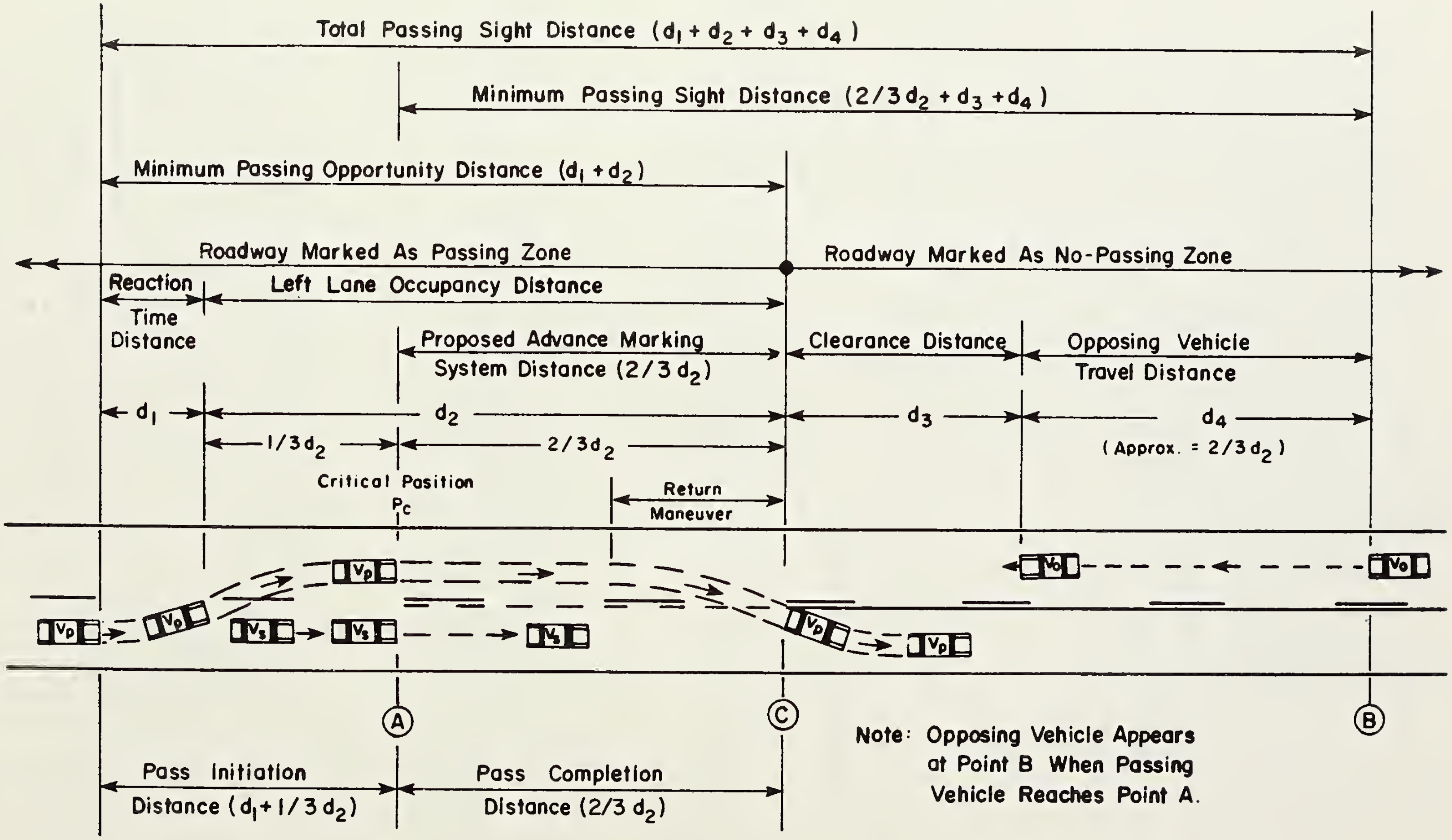

Total Passing Sight Distance ($d_1 + d_2 + d_3 + d_4$)
Minimum Passing Sight Distance ($2/3\, d_2 + d_3 + d_4$)
Minimum Passing Opportunity Distance ($d_1 + d_2$)
Roadway Marked As Passing Zone
Roadway Marked As No-Passing Zone
Reaction Time Distance
Left Lane Occupancy Distance
Proposed Advance Marking System Distance ($2/3\, d_2$)
Clearance Distance
Opposing Vehicle Travel Distance
d_1
d_2
d_3
d_4
(Approx. = $2/3\, d_2$)
$1/3\, d_2$
$2/3\, d_2$
Critical Position P_c
Return Maneuver
V_p
V_s
V_o
A
C
B
Note: Opposing Vehicle Appears at Point B When Passing Vehicle Reaches Point A.
Pass Initiation Distance ($d_1 + 1/3\, d_2$)
Pass Completion Distance ($2/3\, d_2$)

FIGURE 15 SUGGESTED TERMINOLOGY TO DEFINE THE PASSING MANEUVER FOR DESIGN AND MARKING TWO-LANE HIGHWAYS

Since it is at this position that the passing driver must decide to complete or abort the maneuver, it, therefore, defines the location at which information must be provided the passing driver regarding the availability of legal passing distance remaining, and an opposing vehicle that would conflict with the completion maneuver must be able to be perceived at this location. Minimum passing sight distance, thus, should be measured from this point although the marked no-passing zone does not begin until a point downstream where the passing driver must return to the right lane.

Reaction-Time Distance (d_1)

This distance represents the distance traveled during the time that a driver contemplating a passing maneuver makes the decision to initiate the maneuver and maneuvers the vehicle to the point of encroachment into the left lane.

Left-lane Travel Distance (d_2)

Left-lane travel distance represents the total distance traveled in the left lane by the passing vehicle from the point of lane encroachment until returning to the right lane at the completion of the maneuver.

Pass Initiation Distance (d_1+1/3d_2)

Pass initiation distance represents the roadway distance traveled during the maneuver in which a passing vehicle travels from the trailing position to the critical position.

Pass Completion Distance (2/3d_2)

Pass completion distance represents the roadway distance traveled by the passing vehicle from the critical position to the point where the passing vehicle returns to the right lane at the completion of the passing maneuver.

Clearance Distance (d_3)

Clearance distance represents the roadway distance separating an opposing vehicle from the passing vehicle at the time the passing vehicle returns to the right lane.

Opposing Vehicle Travel Distance (d_4)

This distance represents the roadway distance traveled by an opposing vehicle during the time that the passing vehicle travels from the critical position to the point of return to the right lane.

Passing Opportunity Distance (d_1+d_2)

Passing opportunity distance represents the minimum roadway distance in which a passing driver can physically travel from behind the vehicle to be passed until returning to the right lane. It includes the summation of the pass initiation distance ($d_1+1/3d_2$) and the pass completion distance ($2/3d_2$).

Minimum Passing Sight Distance ($2/3d_2+d_3+d_4$)

Minimum passing sight distance represents the minimum sight distance at which a passing driver must first be able to perceive an opposing vehicle from the critical position to permit completion of the pass and provide sufficient clearance distance, d_3. This terminology applies to both the design process and the marking operation for two-lane highways. When available sight distance is less than the minimum passing sight distance value for a selected operating speed, a no-passing zone system is warranted.

Total Passing Sight Distance ($d_1+d_2+d_3+d_4$)

Total passing sight distance represents the summation of pass initiation and completion distance, clearance distance between the passing vehicle and an opposing vehicle at the completion of the passing maneuver, and the distance traveled by an opposing vehicle during the time elapsed while the passing vehicle completes the maneuver from the critical position. It represents the sight distance that must be provided if the passing driver is to be able to perceive, at the point of pass initiation, an opposing vehicle at a sufficient distance to permit safe execution of the maneuver with full visual knowledge throughout that abortion of the maneuver will not be necessary when reaching the critical position.

SUGGESTED DESIGN PHILOSOPHY

Desirable Design for Passing

Designing roadway profile to provide total passing sight distance ($d_1+d_2+d_3+d_4$) from the point of initiation of the maneuver represents a desirable design goal. This assures that an opposing vehicle can be perceived from the initiation point at a sufficient distance to provide the passing driver knowledge that the maneuver will not need to be aborted. Provision of this sight distance cannot be achieved on existing highways without substantial profile modification; however, on new designs, provision of total sight distance will optimize passing operations because manuever aborts due to only visual constraints will be eliminated.

Minimum Design for Passing

Design under minimum passing sight distance conditions will produce a roadway that does not contain any no-passing zones; however, it must be recognized that this choice will produce borderline safety and a substantial number of aborted maneuvers on roadways exhibiting high volumes of traffic.

Design for No-Passing Zones

When proposed roadway design profile cannot economically provide even minimum passing sight distance, no-passing zones must be established. Warrants for establishment of no-passing zones are discussed below.

Passing Opportunity Distance

In evaluating the expected operation of a roadway containing marked no-passing zones, it is suggested that roadway distance between successive no-passing zones less than the minimum passing opportunity distance (d_1+d_2) not be included in computations regarding capacity. The true "passing distance" on a two-lane roadway is determined by two criteria. First, if the unmarked section is less than d_1+d_2, it does not represent a passing opportunity because the vehicle cannot physically execute the maneuver in less than this distance. Second, if the section between successive no-passing zones is long, the actual passing opportunity distance represents the total distance minus the last downstream distance of d_1+d_2. All distances are measured from the adjacent ends of the solid yellow no-passing barrier stripes.

Eye and Object Height

An eye and object height of 3.5 ft (1.07m) is suggested for designing and marking no-passing zones. This height represents approximately the 85th percentile height for current vehicles (16, 35).

SUGGESTED MARKING PHILOSOPHY

Minimum Passing Sight Distance Reference Point

It is submitted that the establishment of no-passing zone systems should be based on minimum sight distance to permit safe completion of the passing maneuver. Therefore, minimum sight distances specified in subsequent warrants are referenced to this position and the needed length of advance treatment downstream from this point is specified. The no-passing barrier stripe would begin after the specified length of advance treatment.

Warrants for Establishment of No-Passing Zones

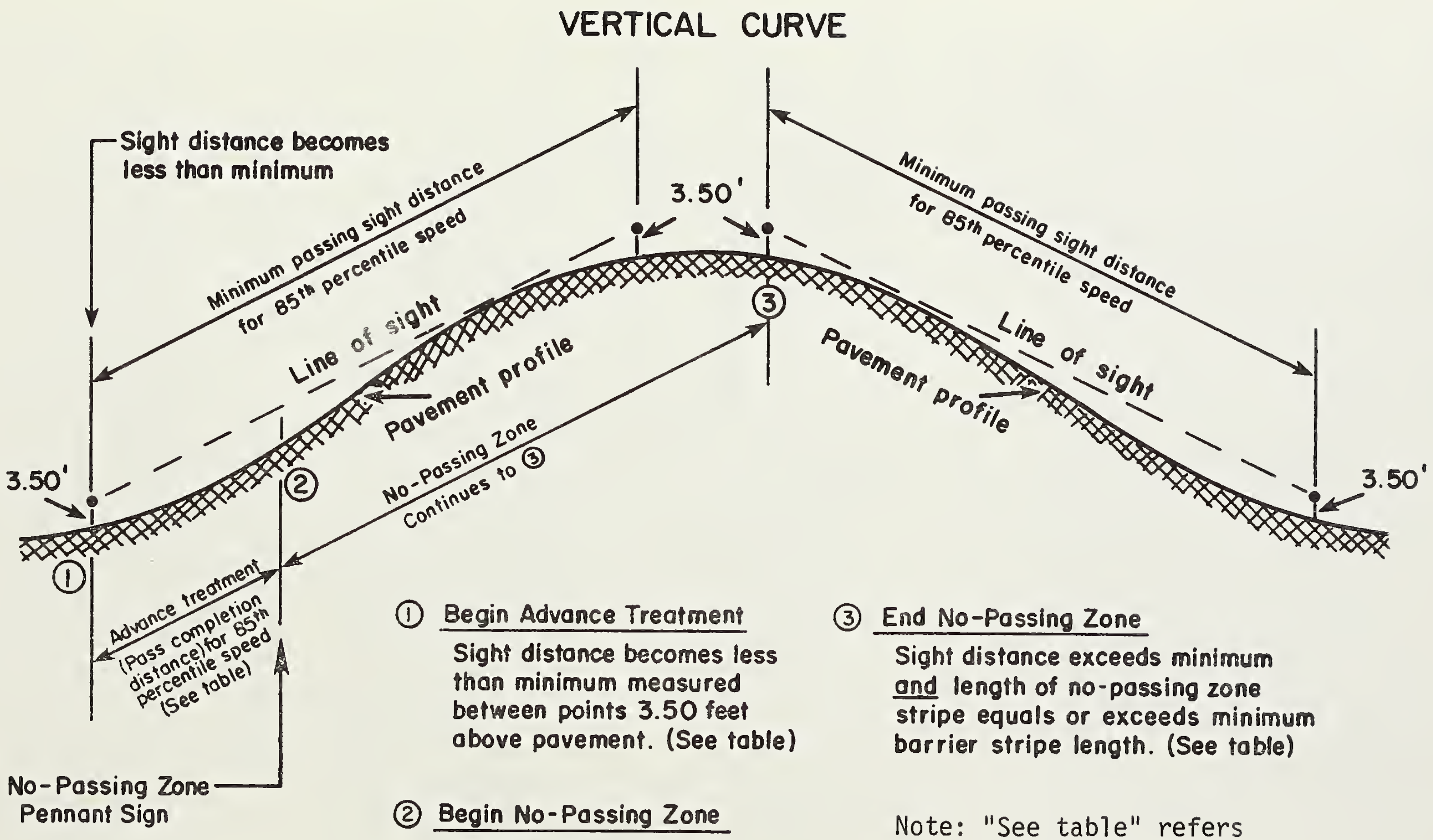
Based on the measured vehicle operations, the concept of minimum passing sight distance and advance treatment developed in this study and the suggested 3.5 ft (1.07m) eye and object height, the following tables present suggested warrants for establishment of no-passing zones. Figures 16 and 17 illustrate the method for locating and determining the limits of no-passing zones and associated advance markings at vertical and horizontal curves.

Table 27 presents suggested minimum passing sight distances, concomitant lengths of the advance marking system, suggested minimum barrier stripe lengths, and minimum passing opportunity distances for capacity determination for a range of operating speeds. The establishment of a no-passing zone system would be warranted on a vertical or horizontal curve when sight distance becomes less than the minimum passing sight distance shown in Table 27 for the selected operating speed. The marking system begins at this point with the application of the advance marking treatment which continues for the distance shown in Table 27.

Establishment of No-Passing Zones

The example presented herein illustrates the application of advance treatment and no passing zones using the minimum passing sight distance warrants presented in Table 27. The 50-mph (80.5 km/h) speed condition is used for illustrative purposes in conjunction with Figures 16 and 17.

1. Using a 3.5-ft (1.07 m) eye and object height and any of several accepted practices to determine sight distance along the roadway between two objects of this height, the beginning point of the no-passing zone system (Point 1, Figure 16 or 17) is established when the sight distance first becomes less than the minimum passing sight distance (Column 2, Table 27) for the selected 85th percentile speed (Column 1, Table 27). For the 50-mph example (80.5 km/h), Point 1 is established when the sight distance becomes less than 1,100 ft (335.3 m) as shown in Column 2, Table 27.
2. The advance dotted treatment begins at Point 1 and continues for a distance of 500 ft (152.4 m) (Column 3, Table 27). This distance represents the pass completion distance for 50 mph (80.5 km/h) operations rounded for design and marking purposes. The downstream end of the advance treatment establishes the beginning point of the solid yellow no-passing zone barrier stripe.


VERTICAL CURVE
Sight distance becomes less than minimum
Minimum passing sight distance for 85th percentile speed
3.50'
Minimum passing sight distance for 85th percentile speed
Line of sight
Pavement profile
Line of sight
Pavement profile
3.50'
②
③
No-Passing Zone Continues to ③
3.50'
①
Advance treatment (Pass completion distance) for 85th percentile speed (See table)
No-Passing Zone Pennant Sign

① Begin Advance Treatment

Sight distance becomes less than minimum measured between points 3.50 feet above pavement. (See table)

② Begin No-Passing Zone

At downstream end of advance treatment (See table) No-Passing Zone pennant sign on left.

③ End No-Passing Zone

Sight distance exceeds minimum and length of no-passing zone stripe equals or exceeds minimum barrier stripe length. (See table)

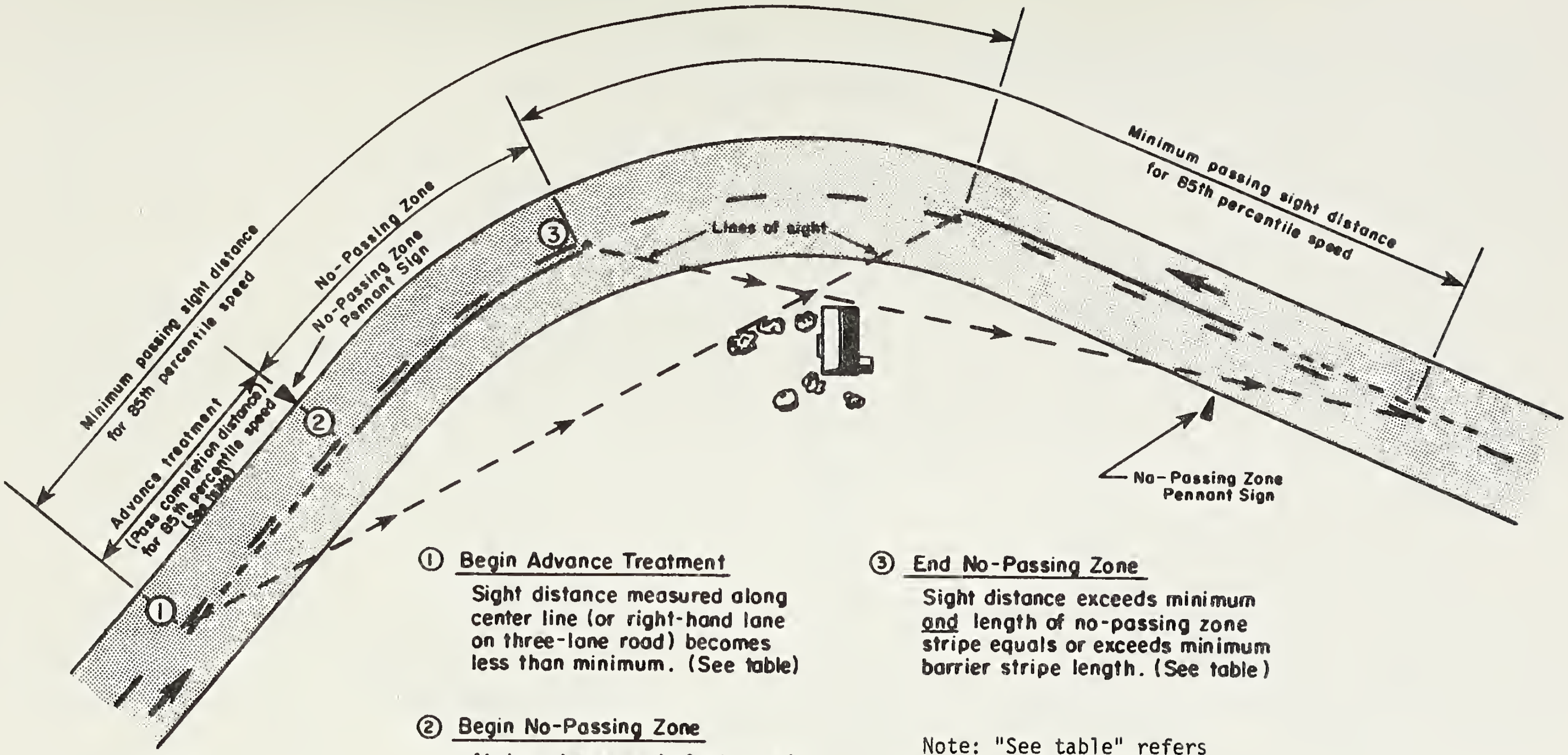
Note: "See table" refers to Table 27

Note: No-passing zone shown for direction of travel ① to ③ only. No-passing zones in opposite directions may or may not overlap, depending on alignment.

Metric Conversion:
1 ft = 0.305 m

FIGURE 16 METHOD OF LOCATING AND DETERMINING THE LIMITS OF NO-PASSING ZONES AND ADVANCE TREATMENT AT VERTICAL CURVES

HORIZONTAL CURVE


Minimum passing sight distance for 85th percentile speed
Advance treatment (Pass completion distance) for 85th percentile speed (See table)
No-Passing Zone
No-Passing Zone Pennant Sign
①
②
③
Lines of sight
Minimum passing sight distance for 85th percentile speed
No-Passing Zone Pennant Sign

① **Begin Advance Treatment**

Sight distance measured along center line (or right-hand lane on three-lane road) becomes less than minimum. (See table)

② **Begin No-Passing Zone**

At downstream end of advanced treatment. (See table)

③ **End No-Passing Zone**

Sight distance exceeds minimum *and* length of no-passing zone stripe equals or exceeds minimum barrier stripe length. (See table)

Note: "See table" refers to Table 27

Note: No-passing zone shown for direction of travel ① to ③ only. No-passing zones in opposite directions may or may not overlap, depending on alignment.

FIGURE 17 METHOD OF LOCATING AND DETERMINING THE LIMITS OF NO-PASSING ZONES AND ADVANCE TREATMENT AT HORIZONTAL CURVES

TABLE 27

SUGGESTED WARRANTS FOR PASSING AND NO-PASSING ZONES

(Column 1) 85th Percentile Speed (mph)	(Column 2) Minimum Passing Sight Distance (ft.)	(Column 3) Advance Marking System Length (ft.)	(Column 4) Minimum Barrier Stripe Length (ft.)	(Column 5) Minimum Passing Opportunity Distance (ft.)
30	350	200	90	300
35	550	275	105	400
40	700	350	120	600
45	900	425	135	700
50	1100	500	150	900
55	1275	550	165	1050
60	1450	600	180	1200
65	1650	675	195	1300
70	1850	750	210	1500

Metric Conversion

1 ft = 0.305 m

1 mph = 1.609 km/h

Note: See example, "Establishment of No-Passing Zones," Item 4(b) in text and Note 3 in Figure 17 for explanation of Minimum Barrier Stripe Length (Column 4 values)

3. The NO-PASSING ZONE pennant sign would be placed on the left side of the roadway adjacent to the upstream end of the no-passing zone solid yellow line (Point 2).
4. The solid yellow no-passing barrier stripe would continue (Point 3) until:
   (a) the sight distance first became greater than the minimum passing sight distance of 1,100 ft (335.3 m) (Column 2, Table 27), but,
   (b) in no case would the solid yellow no-passing barrier stripe be less than the suggested minimum barrier stripe length (Column 4, Table 27) of 150 ft (45.7 m). Adherence to this would assure that a solid yellow no-passing barrier stripe would always be placed downstream from the advance treatment even in those rare geometric situations where the minimum passing sight distance became available rapidly again after beginning the advance treatment. The minimum length of solid yellow no-passing zone barrier stripe is predicated on a two-second driver travel time for the appropriate speed.

Minimum Distance Between Successive No-Passing Zones. Where the distance between successive no-passing zones is less than 750 ft (228.5m), it is suggested that the appropriate no-passing marking (one-direction or two-direction) connect the zones. When the spacing between successive no-passing zones is greater than 750 ft (228.5m), but less than the minimum passing sight distance value in Table 27, it is suggested that the advance dotted yellow line connect the two zones [this applies only the 85th percentile speeds greater than about 40 mph (64.4 km/h)].

CHAPTER 13

WHAT ASPECTS REQUIRE FURTHER STUDY

The concepts developed in this research concerning the suggested design and marking philosophy and the use of advance marking treatment preceding a no-passing zone are innovative concepts that are not included in current design or operational manuals. They have undergone rather extensive review by the Federal Highway Administration, members of the National Advisory Committee on Uniform Traffic Control Devices, (NAC), members of the National Committee on Uniform Traffic Laws and Ordinances (NCUTLO), and traffic engineers from several States. They represent an engineering concept by which the existing process of design and marking no-passing zones may be accomplished on a basis of common operational distances. The criteria for establishing no-passing zones on the minimum passing sight distance from the critical position appear to offer a logical procedure based on satisfaction of driver informational needs. The advance marking system in conjunction with the left-side positioned no-passing zone pennant indicates a high level of understanding by drivers in addition to exhibiting required visual attributes and desirable placement and maintenance characteristics. The cost analyses indicate that favorable benefits may be realized by application of the advance treatment on a nationwide basis.

From an engineering viewpoint, the suggested criteria and warrants developed in this research appear to provide increased safety in the execution of the passing maneuver on rural two-lane highways. Sound engineering rationale represents only the first step toward modification of a nationwide system. Several factors are discussed below that must be considered in attempting to define the total system and to assist in implementation of the concepts produced in this study. These factors represent the next steps in the process of applying research findings.

FULL-SCALE FIELD TESTING

Although the cost analyses indicate that the suggested demarcation system will provide favorable benefits, and the human factors studies indicate a high level of understanding, it is believed that field testing under real-world operating conditions is necessary in order to evaluate driver response and to measure the benefits directly. The need for field testing was strongly advocated by the attendees at the review workshop (53) if the cost analyses indicated favorable cost-benefit ratios.

There was general agreement at the workshop to review the research findings that the proposed advance treatment should be field tested before recommendations were made regarding adoption as a national standard. Mr. Kearney, Executive Director of the National Committee on Uniform Traffic Laws and Ordinances, an attendee of the review workshop charged with the responsibility of reviewing the legal aspects of the research, has suggested that any State desiring to conduct such a test could adopt the following model law:

> *The (State highway commission) and local authorities on highways under their respective jurisdiction may install any traffic control device to test its effectiveness as part of an approved experiment even though it is not in the manual approved under ________________________ (cite law comparable to § 15-104 of the Uniform Vehicle Code.)*

MODIFICATION TO MANUALS

The design process, the marking process, and the vehicle codes are all affected by the concepts developed herein. Applicable sections of the AASHTO design policy, the MUTCD, and the Uniform Vehicle Code and Model Traffic Ordinance will require modification prior to adoption of the suggested concepts. Drafting of the official wording is considered to be beyond the scope of this research study and should be accomplished by personnel charged with this responsibility; however, sections of the three documents that are affected by the concepts proposed in this research are identified in the following sections.

A Policy on Geometric Design of Rural Highways (21)

Passing sight distance design criteria and recommendations are presented in pages 140 through 151 (21). The sections affected by this research include the following:

- Criteria for Design
- Design Values
- Effect of Grade on Passing Sight Distance
- Frequency and Length of Passing Sections
- Criteria for Measuring Sight Distance
- Measuring and Recording Sight Distance

Manual on Uniform Traffic Control Devices for Streets and Highways (3)

The sections of the current MUTCD affected by the research results include the following:

- Section 3A-7 -- Types of Longitudinal Lines
- Section 3B-1 -- Center Lines
- Section 3B-3 -- No-Passing Zone Markings
- Section 3B-4 -- Application of No-Passing Zone Markings
- Section 3B-5 -- Warrants for No-Passing Zones at Curves.

Uniform Vehicle Code and Model Traffic Ordinance (38)

Kearney, in reviewing the proposed advance treatment, indicates that:

> *Because most states do not now define the meaning of any centerline, it should not be necessary to enact legislation providing for the Texas Transportation Institute advance marking system.*

Although ten States have laws defining the color and meaning of certain centerlines, Kearney's review indicated that most of these ten laws dealt only with markings used to indicate a no-passing zone which would not be changed by the proposed advance marking system. Only the Hawaii law defines the meaning of other roadway markings, according to Kearney; thus only Hawaii should consider amending its law if the advance marking system were to be used.

The suggested 750 ft (229 m) minimum distance between successive no-passing zones received considerable expressed concern by some reviewers, primarily those attendees from States containing severely rolling or mountainous terrain where slow-moving vehicles were prevalent. Concern was expressed that, on highways in mountainous terrain containing many no-passing zones, drivers frequently were trapped behind trucks or other vehicles moving at speeds from 6 to 12 mph (9.66 to 19.31 km/h) and that even the current 400 ft (122 m) minimum distance between successive no-passing zones created difficulties in providing "passing zones" on these highways. The minimum distance suggested in this research represents the operating distance actually needed to pass a 20 mph (32.2 km/h) vehicle by a high-powered vehicle, and if no-passing zones are to be predicated on "safety," this distance is strongly advocated. Kearney suggests an alternative to the problem which involves classification of "obstruction" in the Uniform Vehicle Code. Section 11-301 of the Uniform Vehicle Code requires driving on the right side of the roadway except:

> *When an obstruction exists making it necessary to drive to the left of the center of the highway; provided, any person so doing shall yield the right of way to all vehicles traveling in the proper direction upon the unobstructed portion of the highway within such distance as to constitute an immediate hazard.*

Discussion with State traffic engineers (53) indicated that quite often a truck traveling in the 6-to-12 mph speed range (9.7-to-19.3 km/h), and in most cases, less than 15 mph (24.1 km/h), was the characteristic vehicle prohibiting passing on two-lane roads in severe terrain. Mr. Kearney suggested that if a vehicle traveling at this slow speed constitutes an "obstruction," an overtaking motorist could lawfully pass even in a marked no-passing zone. He suggested, that to make this clear, the above provision could be amended by addition of the statement:

> *For purposes of this subsection, any motor vehicle moving at a speed of 15 mph (24.1 km/h) or less shall constitute an obstruction outside an urban district.*

If this change were made, the engineer could close up successive no-passing zones. Instead of using a dashed centerline, this area would contain no-passing zone markings. Nonetheless, a trapped motorist could lawfully pass a vehicle moving 15 mph (24.1 km/h) or less if it were safe to do so. Conversely, it would not be lawful to pass a motor vehicle moving faster than 15 mph (24.1 km/h) in accordance with Mr. Kearney's suggestion.

Although the inclusion of a vehicle moving less than 15 mph (24.1 km/h) in the definition of an "obstruction" may represent a legal circumvention of the problem, it is pointed out that safety problems can occur from the operational aspects that may be expected. Drivers in Charleston and Cedar Rapids (61), when asked to define a "slow" vehicle, considered a "slow" vehicle to be one traveling considerably faster than 15 mph (24.1 km/h). Only about 28 percent of the subject drivers considered a "slow" vehicle to be one traveling less than 20 mph (32.2 km/h) and only about 5 percent considered it to be traveling less than 10 mph (16.1 km/h). These data indicate that many drivers would consider a vehicle traveling much faster than the suggested 15-mph speed (24.1 km/h) as being "slow;" consequently the driver interpretation could be that such a vehicle constitutes an "obstruction" also, and a passing maneuver might be attempted. Compliance with the suggested 15 mph (24.1 km/h) upper speed limit for an "obstruction" is believed to require extensive driver education and would be extremely difficult to enforce.

OTHER CRITERIA FOR SPECIAL GEOMETRIC SITUATIONS

A majority of passing-related accidents were found to occur at rural intersections or driveways. It is believed that special demarcation systems may be necessary for use at these geometric situations. The normal rural environment conditions a passing driver to expect potential conflict only from opposing vehicles downstream. Intersections introduce vehicle maneuvers which interrupt this expectancy condition. The conceptual demarcation systems resulting from this research study apply to designation of no-passing zones for the normal rural passing maneuver in which an opposing vehicle constitutes the potential constraining factor; however, special geometric constraints such as intersections, bridges, railroad grade crossings, and driveways may necessitate development of appropriate supplemental demarcation systems and warrants for their installation.

PART II RESTRICTIVE PASSING ZONES

CHAPTER 14

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

One phase of the research study concerned investigation of and concomitant recommendations for use of a roadway demarcation system that might be used to designate zones where passing is discouraged but not prohibited -- in particular, the use of a single solid yellow centerline. For purposes of definition, this type of operation is termed "restrictive" passing as opposed to "prohibitive" wherein drivers may not legally pass. The single solid yellow centerline is used currently in several urban areas with differing local interpretation and enforcement policies regarding intended driver response with respect to passing across it. The emphasis in this research study was directed toward evaluating the use of the single solid yellow centerline on urban two-lane streets and on rural highways such as winding mountainous roadways or in rolling terrain where reoccurring sight distance limitations would necessitate substantial marking for prohibitive passing under classical opposing-vehicle sight distance criteria. The philosophy on which potential use of a restrictive passing zone on rural highways is based is that an automobile with appreciable acceleration capabilities may overtake a slow-moving truck, and adequate sight distance may be available to pass at the lower speed but not at the higher speed limit and/or operating speed of the roadway.

The research problem statement delineated that four questions be addressed in this phase of the passing/no-passing study:

1. Is there a need for a restrictive passing zone marking?
2. Can a marking be devised to discourage, but not prohibit passing?
3. What is the effect of using such a marking, i.e., is it beneficial to the current standard marking for passing and no-passing zones?
4. Can drivers accurately interpret the meaning of such a marking in relation to the new use as well as other uses of the solid yellow line?

Human factors laboratory studies were developed and administered to obtain information regarding driver understanding and interpretation of the single solid yellow line to form a factual basis with which to answer questions 2, 3, and 4 above. (Question 1 was addressed through accident analysis and discussion with traffic engineers at workshops (19, 53) during the research study.) This section documents the human factors laboratory study development, administration, and data reduction. Evaluation of the findings is presented in Chapter 15.

RESEARCH APPROACH

The single solid yellow centerline currently is used extensively in two cities -- Cedar Rapids, Iowa, and Charleston, South Carolina, and only on very limited areas of rural two-lane highway. The approach taken to evaluate the extension of this system from the urban environment to the rural environment involved identification of the reasons for which its use was selected by the two responsible agencies; identification of attributes or disadvantages from an operational, enforcement, and legal liability aspect; determination of driver understanding and interpretation of legal intent of the marking familiar to them in the urban environment and then in comparison to the same marking system encountered in a rural environment.

The evaluation process included site visitations to both Cedar Rapids and Charleston by the research staff to discuss the unique marking system attributes with traffic engineers of the two cities. In addition, supervising police officers in both cities were questioned concerning enforcement policy regarding passing operations with respect to the single solid marking. Accident data on single solid yellow marked streets were obtained from Charleston and statistical analyses were conducted to determine the influence of several operational and geometric characteristics on accident causation. These data were compared to accident rates observed on streets marked with dashed yellow centerlines in a third city. Laboratory slide-tape studies were administered to drivers in both Charleston and Cedar Rapids to determine understanding of the single yellow line in both urban and rural environments. Since the single solid line usage in the rural environment was intended for lower speed situations, the laboratory studies included attempts to define "low speed" from a driver's viewpoint both in terms of discrete speed quantification (XX mph) and interpretation of the word "slow" if viewed on a sign.

The opinions of State police were solicited to identify enforcement problems that they foresaw in application of the restrictive passing concept on rural highways. The concept was discussed with State enforcement personnel, State and local traffic engineers, and attorneys in a two-day workshop (19) to obtain opinions regarding its usage with respect to driver safety, enforcement, and liability aspects. The interim recommendations were reviewed by the FHWA, members of the National Advisory Committee on Uniform Traffic Control Devices (NAC), and the National Advisory Committee on Uniform Traffic Laws and Ordinances (NCUTLO) in a two-day workshop (53).

Human Factors Laboratory Study Development

The single solid yellow centerline is used extensively in two cities -- Cedar Rapids, Iowa, and Charleston, South Carolina. Since drivers from these cities were accustomed to widespread use of the single solid yellow line in the urban area, it was considered logical that, of any sample of subjects, they could be most expected to interpret the marking intent in a rural environment.

The laboratory studies were developed to address specific questions regarding driver interpretation and understanding of certain conventional roadway markings and of possible new marking and signing systems; the legal interpretation with respect to specific operational maneuvers; and preferences for alternative methods to display information.

The study consisted of two data forms to be completed by participating drivers. The first of these forms, the Driver Information Form, was designed to obtain demographic information from the subjects including a record of the states and countries in which each subject had driven. This information was obtained to provide data with which responses of drivers with varied educational background and driving experience could be compared. The primary instruments of the laboratory studies, however, were the response forms on which subject drivers answered specific questions during a slide-tape audio-visual presentation of markings and signs.

Four laboratory studies were developed, designated studies number 1, 2, 3, and 4. The slide-tape script, slide description, driver information form, driver response forms, and tabulated responses to each question are documented individually for the studies in Appendices E, F, and G of Reference 61.

The laboratory studies were developed to determine driver understanding and/or interpretation of:

1. the legal intent of the single solid yellow centerline in the driver's city (this question was asked with no mention of "passing" or "no-passing" in the introductory remarks to determine if this connotation was illustrated by merely the marking itself).
2. what maneuvers were considered safe across or alongside the single solid yellow centerline
3. the legality of passing across the single solid yellow line under various operational situations (slow vehicle, stopped vehicle, etc.)
4. the legal intent of other conventional centerline markings with respect to passing, given merely the marking and also various operational situations. These questions were asked to form a basis for evaluating the driver understanding of centerline markings that exist throughout the nation.
5. the difference in meaning between the single solid yellow line and conventional centerline markings with respect to passing.

The above questions were developed to consider driver response when the markings were placed on an urban street and also on a rural two-lane-highway. The intent of the single solid yellow centerline with respect to passing is diametrically opposite between the two cities. In Charleston, passing is legally prohibited across the marking; in Cedar Rapids, passing is permitted legally but discouraged. Since drivers in both cities were naive regarding the intended meaning of a single solid yellow centerline on a rural two-lane highway, presentation of similar questions to subjects from both cities would be expected to identify expectancy differences based on their understanding of the intent in their particular city. The common reference base would be a comparison of their respective deduced meanings in a rural environment to their understanding of conventional (nationwide standard) single dashed yellow centerline, double solid yellow centerline, and one-directional no-passing zone marking.

In addition to determining driver understanding and interpretation of pavement markings, questions were developed to determine:

1. what speed of a vehicle drivers considered "slow"
2. if a sign message could be designed to denote, without specifying a specific speed value, when passing would be permitted and when it should not be attempted due to limited sight distance availability
3. if specific speed information was necessary to clearly identify to a driver the conditions under which restrictive passing zones were to be used, how could this information best be displayed for clarity of meaning
4. which shape of the sign blank was preferred by drivers if restrictive passing zone information was to be displayed on signs.

Human Factors Laboratory Study Administration

The laboratory studies were administered in a similar manner to all subjects. To avoid bias in instructional information that might occur among separate administrations by various individual test administrators, a synchronized slide-tape technique was used. Therefore, all subjects received the same instructions, slide order and response time. No additional information regarding the study objectives was presented to the subjects until after completion of the study.

Studies 1 and 2, both identical except for location of subjects, were administered in Charleston, South Carolina (Study 1) and Cedar Rapids, Iowa (Study 2). Appendix E (Ref. 61) contains the scripts, slide description, and answer forms for these two studies. The studies were administered to 47 subjects in Charleston and 29 subjects in Cedar Rapids.

After preliminary analysis of the results of studies 1 and 2, two additional studies (Studies 3 and 4) were developed and administered separately to subject drivers in Cedar Rapids, Iowa. Study 3 was administered to 34 subjects; study 4 was administered to 39 subjects.

Study 3 concerned driver interpretation of markings in both the urban and rural environment. Study 4 concerned only rural two-lane highways. Both studies concerned driver evaluation of signing techniques for rural highways information display.

Details of the slide-tape script, the slide description, and the answer forms are presented in Appendices F and G, Reference 61, for studies 3 and 4 respectively.

CHAPTER 15

EVALUATION OF SINGLE SOLID YELLOW CENTERLINE

MEANING OF THE SINGLE SOLID YELLOW LINE IN URBAN AREAS

The legal intent of the single solid yellow line in Cedar Rapids is that turning left across to enter a driveway entrance is permitted and passing is permitted. The solid yellow line with respect to passing is analogous to the solid white line with respect to crossing; each permits the respective maneuver but is intended to convey an increased degree of potential hazard, thus, necessitating increased caution by the driver. The single solid yellow line is used exclusively throughout Cedar Rapids (no dashed yellow centerlines are used) on two-lane streets. Double solid yellow lines are used on all four lane undivided streets. Three-lane streets including reversible flow streets are marked with the single solid yellow line system.

In Charleston, South Carolina, a different legal intent is associated with the single solid line. The double yellow marking prohibits crossing and passing, and the single solid line permits crossing but prohibits passing. Thus the solid yellow line in this city is considered prohibitive rather than restrictive which is directly analogous to the accepted intent of the solid yellow line on the rural highway. Enforcement policy, however, is slightly more lenient than the legal intent might imply. Supervisory police stated that passing on urban streets was viewed in light of the circumstances at the site; for example, a citation probably would be issued to a driver who deliberately passed across the line in the absence of some unusual situation such as a stopped or very slow-moving vehicle, or if the passing maneuver was basically unsafe. General guidelines were that citations would not be issued if only part of the passing vehicle crossed the line (straddle) to move around a vehicle that was impeding traffic flow severely. In Charleston, the single solid yellow line is used on narrow two-lane streets where access to the left is required at frequent intervals and occasionally on suburban streets to indicate no-passing. Most primary roadways are marked with double yellow solid lines when passing is specifically prohibited.

EXPERIENCE WITH THE SINGLE SOLID YELLOW LINE ON URBAN STREETS

Narrow two lane, two way urban streets present special problems to city traffic engineers. Desirable smooth traffic flow is traumatized by the need for frequent access to adjacent property. Slow turning vehicles create a situation that makes passing desirable by through vehicles. High-volume traffic combined with frequent turns, however, produces hazardous passing conditions. A marking system -- the single solid yellow centerline -- which would restrict but not prohibit passing under these conditions has been proposed to alleviate the problem. The single solid yellow centerline offers three distinct advantages:

1. Minimum pavement space is consumed by the marking system;
2. The solid line offers a strong psychological barrier to the motorist and connotes increased caution in crossing;
3. Passing of slow-moving vehicles is discouraged but not legally prohibited. Since a driver will pass a turning or stopped vehicle on an urban street regardless of the legality of the marking system present, rather than remain stopped in the lane, the use of a restrictive marking system reduces the enforcement problem.

Conversely, the use of the standard dashed yellow centerline does not legally restrict passing and therefore, could create a hazardous situation. The use of the standard double yellow centerline consumes valuable travel lane space on narrow streets and produces a situation in which the motorist must violate the law when passing a stopped vehicle or to move around a slow-turning vehicle. This places a great deal of pressure on enforcement agencies to ignore illegal maneuvers unless some type of incident results. For these reasons, the use of a restrictive marking system for two-lane two-way urban streets exhibits considerable appeal to those responsible for urban traffic control.

Accident Experience on Urban Streets

In order to evaluate the accident experience where the single solid yellow centerline is used, eleven street sections in Charleston, South Carolina were selected representing a wide variety of adjacent land development.

These sections ranged in length from approximately 0.1-mile (0.161 km) to slightly over 1 mile (1.609 km). The following data were obtained for each site:

1. Study site length
2. Type of development
3. Width of roadway
4. Parking configuration
5. Number of curb openings in the section
6. Average daily traffic
7. Number of crossing-the-centerline accidents in 1975 and 1976

The resulting data were normalized by converting the site parameters to equivalent values per mile and accidents per million-vehicle-miles. A complete summary of these data is presented in Table 28. From Table 28 it can be seen that the accident rate ranges from a low of 0.0 to a high of 11.76 accidents per million-vehicle-miles; the average accident rate is 3.92 accidents per million-vehicle-miles. Using the critical rate analysis procedure illustrated in Table 28 three of the study sections exceeded the critical rate, therefore, exhibiting an unusually high accident rate when compared to the mean.

Regression analysis of all variables collected on the Charleston study sites revealed that the most significant contributing variables to the observed accident rate were (1) type of development, (2) average daily traffic, (3) number of driveway openings per mile and, (4) width of the pavement surface. The resulting model is:

$$A = -6.319 + 0.331\,W + 0.016D - 0.048\,V + 8.318\,T$$

where:

A = accident rate per million-vehicle-miles
W = street surface width, ft
D = number of driveway openings per mile in direction of traffic
T = type of development (residential, commercial, etc., see Table 28)
V = average daily traffic

The strength of the regression model ($R^2 = 0.66$) indicates that the model can account for about 66 percent of the variability in the observed accident rate. Desirably, about 80 percent of the variability should be accounted for by a

TABLE 28

SUMMARY OF SITE DATA -- CITY OF CHARLESTON, SOUTH CAROLINA

Site Number	Development	Curb to Curb Width	Lane Width	Striping System Used	Parking System	Number of Driveways	Posted Speed (MPH)	ADT 100's	Number Of Midblock Accidents			Date Marking System Installed	Location Descriptor			Section Length (Miles)	Total Accidents 2¼ yrs	Total V-M Travel x10⁶	Accident Rate A/MVM	Average Driveway Openings Per Mile	Comments
									'75	'76	'77		Street	From	To						
1	King to E. Bay Comm. Remainder Residential	42'	14'	SSY	Parallel Both Sides	61	30	95	14	15	4	75	Broad St.	Lockwood	East Bay	1.032	33	8.95	3.69	59.1	Downtown Street
2	Residential	30' 22'	15' 11'	SSY	No Parking Cal. → Bull Parking Both Sides	35	30	25	0	1	0	"	Barre St.	Calhoun	Broad	0.540	1	1.23	0.81	64.8	Fringe Street
3	Residential	27'	10'	SSY	Parallel One Side	32	30	35	4*	0	0	1/76	George St.	Coming	Anson	0.388	4* 0^{++}	0.74^{++}	0^{++}	82.5	Fringe Street
4	Low Income Residential	30'	9'	SSY	Parallel One Side	10	30	30	1	2	2	75	Columbus St.	Meeting	E. Bay	0.360	5	0.99	5.05	27.8	Fringe Street
5A	Mixed Residential And Commercial	30'	9'	SSY	Metered PP Both Sides	2	30	15*	1	1	0	"	Charlotte	Elizabeth	Meeting	0.123	2	0.17	11.76	16.3	Downtown Street
5B	Commercial	24'	10'	SSY	Parallel One Side	6	30	20*	0	1	1	"	Hutson	Meeting	King	0.114	2	0.21	9.52	52.6	Downtown Street
5C	Residential	27'	9'	SSY	Parallel One Side	29	30	28	0	0	0	"	Vanderhorst	King	Rutledge	0.445	0	1.14	0	65.2	Downtown Street
6	High Density Residential	24'	9'	SSY	Parallel One Side	30	30	12*	0	2	0	"	New St.	Tradd	Broad	0.170	2	0.19	10.53	176.5	Downtown Street
7	Residential	24'	9'	SSY	Parallel One Side	26	30	52	0	0	0	"	Wentworth	E. Bay	Meeting	0.180	0	0.85	0	144.4	Fringe Street
8	Mixed Residential And Commercial	27	10'	D-Y	Parallel Both St. Paul to King	29	30	18	1	0	1	"	Radcliff	King	Rutledge	0.426	2	0.70	2.86	68.1	Fringe Street
9	Residential	36	11'	SSY	Parallel Both Sides	22	30	110	2	2	0	"	East Bay	Broad	Water	0.294	4	2.95	1.36	74.8	Fringe Street
10	Residential	36	18'	SSY	Parallel Both Sides	36	30	180	0	3	0	"	Meeting	Broad	S. Battery	0.322	3	5.29	0.57	111.8	Fringe Street
11	Commercial	30'	9'	DSY	Parallel One Side	9+RR	30	55	0	1	0	"	Columbus	Meeting	King	0.133	1	0.67	1.49	67.7	Downtown Street
12	Residential	33'	16½'	SSY	Parallel Both Sides	147	30	90	8	5	2	"	Rutledge	Mt. Pleasant	Race	1.061	15	8.71	1.72	138.5	Predominantly turning accidents North Charleston Area Suburban
13	Residential	32'	12'	SSY	Parallel One Side	120	30	85	5	1	2	"	King	Caroline	Mt. Pleasant	1.106	8	8.58	0.93	108.5	
14	Residential	26'	13'	SSY	Parking Both Sides	77	30	33	0	0	2	"	Huger	Haygood	King	0.636	2	1.92	1.04	121.1	
						633**													3.92**	93.5**	

Vehicle Miles of Travel = 365 x ADT x 2.5 x Section Length

* One way operation in 1975

** SSY only

++ Based on 1½ years accident data

+6 months of data only in 1977

SSY - Single Solid Yellow

D-Y - Dashed Yellow

DSY - Double Solid Yellow

Metric Conversion:

1 ft = 0.305 m

1 mile = 1.609 km

1 mph = 1.609 km/h

Critical Rate

$r_c = 3.92 + 1.282\sqrt{\frac{3.92}{1}} - 0.5$

$r_c = 5.96$ A/MVM

regression model if it is to be used for predictive purposes (55); thus, the model is at best marginal for predictive purposes.

For comparison, similar data were obtained in Garland, Texas for narrow two-lane streets marked with dashed yellow centerline. Eleven sites were selected with average daily traffic volumes ranging from 1500 to 12,000 vehicles per day. The length of the study sections varied from 0.5 mile to 1.5 miles (0.805 to 2.414 km). A summary of the data for the Garland sites is presented in Table 29.

The observed accident rate varied from 0.42 to 7.76 accidents per million-vehicle-miles with an overall average of 2.96 accidents per million-vehicle-miles. The critical rate analysis reveals that at the 90 percent confidence level, only two of the eleven sites exceeded the critical rate of 4.67 accidents per million-vehicle-miles.

This comparative analysis indicates that there is essentially no difference in accident rate on two-lane two-way urban streets that can logically be attributed to the type of marking system being used. The mean accident rate and the range of rates is somewhat higher in the Charleston data than for comparable data from Garland. This is attributed to the differences in available roadway width.

Box and Associates (56) indicate that the expected accident rate for urban streets with little access control is about 5.26 accidents per million vehicle-miles. This is somewhat higher than the observed average in each city from which data were obtained. This suggests that both marking systems studied may well exhibit accident rates below the expected average of all roadways of that type.

Investigation of the Attributes of the Single Solid Yellow Line on Urban Streets

The 1971 MUTCD does not include provision for use of a single yellow centerline. Meyer (57) in a paper presented at the Institute of Traffic Engineers Conference in Kansas City, Missouri (1972) stated the following question:

> *Does omission of the single solid yellow center line provision leave the Traffic Engineer with a condition that cannot be appropriately handled, when a provision did exist for like conditions in the 1961 and 1970 DRAFT MANUAL: What type of center line should be used within urban areas on a two lane two way street where conditions do not permit open passing or require total prohibition of passing?*

TABLE 29

SUMMARY OF SITE DATA -- CITY OF GARLAND, TEXAS

Site Number	Development	Curb To Curb Width	Lane Width	Striping Used	Parking System	Posted Speed	ADT 100's	Number of Midblock Accidents	Section Length	Accident Rate
15	Residential (One Side)	22'	11'	D-Y	None	35	88	2	0.631	2.29
16	Rural	22'-25'	11'-12'	D-Y	None	40	19	7	1.557	6.50 *
17	Residential (One Side)	20'-22'	10'-11'	D-Y	None	40	68	1	0.970	0.42
18	Residential (One Side	36'	12'	D-Y	Parallel	35	61	4	0.964	1.86
19	Suburban	34'	13'	D-Y	None	45	12	3	1.008	0.68
20	Residential (One Side)	36'-40'	12'	D-Y	Parallel	30	39	5	1.064	3.28
21	Residential (One Side)	36'	12'	D-Y	Parallel	30	15	1	0.523	3.43
22	Industrial	40'	12'	D-Y	Parallel	30	21	3	0.511	7.76 *
23	CBD	36'	12'	D-Y	Parallel	30	38	3	0.600	3.56
24	Residential (One Side)	30'-32'	12'	D-Y	None	35 & 40	67	3	1.585	0.77
25	Residential & Park Land	22'	11'	D-Y	None	35	50	3	0.831	1.99

$\Sigma = 32.54$

$r_a = 2.96$

$r_c = 2.96 + 1.282\sqrt{2.96} - 0.5$

$r_c = 4.67$ A/MVM

COMMENTS

85th percentile speed 48 mph

Parking permitted but rare

Parking restricted 7 am to 7 pm

D-Y -- Dashed Yellow Centerline

Metric Conversion:

1 ft = 0.305 m

1 mile = 1.609 km

1 mph = 1.609 km/h

* Significantly different at the 90% confidence level.

To evaluate the potential attributes of the single solid yellow line as an urban marking, Meyer administered a survey to 250 city and county traffic engineers throughout the nation. In analyzing the results, Meyer considered the application and benefits of the single solid yellow centerline under twelve circumstances. These are paraphrased below with comments provided in light of research findings from the subject study and experience throughout the nation.

Question 1. How is the approach to an intersection marked with the skip single yellow center line to discourage lane changing or passing? Is the skip widened for additional emphasis, or is a double solid yellow used which prohibits passing, and how often is this decision necessary?

Comment: If particular intersections exhibit passing-related problems, the double solid yellow generally is applicable. Widening the dashed line may be understood by some to connote increased hazard, however, discussion with drivers in this and other research studies indicates that the intent of emphasis is too subtle for most drivers.

Question 2. Is the narrow roadway further restricted in lane width when use of the double yellow center line is required at those locations where use of the skip yellow center line inviting open passing is not advisable?

Comment: Travel lane width is reduced further by a double line system than by a single line; however, line width and spacing may be decreased to partially offset the restriction. The connotation that the dashed yellow line invites open passing is incorrect. Drivers repeatedly stated in this study that the centerline on urban streets denoted lane separation primarily and that they did not interpret it to convey passing prohibition; they did not consider passing to be a major concern on urban streets due to the vastly different operational constraints in the traffic and geometric situations prevailing. The accident analysis indicated no appreciable difference in accident rate between single solid yellow and dashed yellow centerline.

Question 3. Does uniformity of the meaning of center line markings exist in the urban and rural area? That is, does the skip yellow mean that the passing sight distance is adequate in the city as it does in the rural area? Does the skip yellow, perhaps, invite and permit open passing, when, in fact, frequent cross streets, driveways, pedestrians and parking activity, provide an effective sight distance far less than the requirements for a no passing zone?

Comment: As stated in the previous comment, drivers interpret the urban two-lane marking as a travel-lane divider. The dashed yellow line, even on urban roadways, does not permit open unrestricted passing; the decision burden is placed on the driver to execute a safe pass. Drivers apparently execute equal caution (or lack of it) with either the dashed yellow centerline marking or the single solid yellow centerline. The dashed yellow means the same thing in the urban environment as in the rural environment -- traffic is traveling in opposite directions on both sides of the line, and a driver may cross the line to pass if the maneuver does not interfere with another vehicle. Drivers, however, generally do not pass at high speed in a congested urban traffic/pedestrian environment; if they cross the centerline to pass, it usually is to pass a very slow-turning or stopped vehicle and passing speeds are not high.

Question 4. How does the Traffic Engineer handle the markings on a city street with peak hour parking restrictions which change from two lanes in off peak to four lanes during peak hours? Is a skip or a double solid yellow to be used -- when it is not advisable to permit open passing during four lane operation nor prohibit passing during two lane off peak?

Comment: Four-lane undivided streets should be marked with a double yellow centerline regardless of parking restrictions. Reasonable enforcement policy regarding crossover to pass a parking or departing vehicle during the hours that the street is operated as a two-lane street would appear to alleviate problem. "Open" passing during four-lane operation would be undesirable and probably almost impossible due to insufficient gaps -- if traffic volumes are high enough to dictate four lane operation, passing would not be a viable driver choice. Under none but the most unique conditions would passing in the third lane be acceptable, and then only when the two lanes were blocked by some incident, and under site control.

Question 5. Hasn't the 1970 Manual use of skip yellow replaced the 1961 Manual single solid white and didn't the single solid white center line mean "discourage," and now the skip yellow means "openly permissive?"

Comment: The dashed yellow replaced the dashed white to convey opposing travel direction on either side. While it is true that the solid yellow line is interpreted almost universally as "do not drive to the left," the solid white remains a viable marking as a marking on uni-directional roadways (such as left or right turn-bays) to emphasize the caution of crossing. Observation in urban areas demonstrates that, regardless of the marking system present, a driver will cross the marking if the situation so dictates.

Question 6. How is the transition from the single solid white to the skip yellow to be made? While many Traffic Engineers may admit no single solid white center lines existed at the beginning of the 1972 season, the city with an extensive thermo or cold plastic program has a different problem?

Comment: Solid white centerlines are not permissable on two-lane roadways because of the intended meaning of yellow and white to denote travel direction. Admittedly, the changeover from existing white non-paint lines to yellow is a real-world problem presenting economic constraints; however, Mr. Meyer's stated problem is not related to driver understanding or safe traffic operations with respect to the marking system.

Question 7. On the one way street, can a motorist always depend on recognizing the color to determine if it is one way or two way? Can color be distinguished during all roadway conditions? Can skip yellow be clearly defined from skip white at night and in the critical period when the surface is wet?

Comment: Visibility studies have indicated that visual characteristics between the yellow and white lines are not appreciably different; however, whether or not the majority of drivers recognize the intent conveyed by yellow versus white is an educational problem. Signs indicating one-way travel are considered necessary even on freeway service roads by many traffic engineers, perhaps because they believe drivers do not recognize the difference between colors, perhaps because they believe the target value of a sign is necessary particularly in inclement weather.

Question 8. Is the 1970 Manual provision a trend toward international pavement markings, when in fact, the international standards provide for use of a single or double solid longitudinal line? Should the trend toward international standards be pursued when in fact the U.N. Convention (International Manual) permits either or both white and yellow colors for longitudinal markings without assignment of color meaning?

Comment: No comment is presented regarding international standard policy.

Question 9. Would the single solid yellow center line be confusing to the motorist? That is, would it be any more confusing than the single solid white center line was in the 1961 Manual or the single solid white lane line is in the 1970 Manual?

Comment: Driver understanding studies discussed later in this document indicated that a majority of drivers did not recognize that the single solid yellow line on urban streets where it is used meant restricted passing. In fact, most drivers interpret the solid yellow line to mean "no-passing." The fact remains, however, that they do not pass on two-lane urban streets regardless of marking unless they are forced to the other lane to move around a partial or full lane blockage and then under different expectancy conditions.

Question 10. Is the skip yellow center line really more economical than the single solid yellow center line, even when the alternate may be the double solid yellow center line involving twice the material quantity as a single solid yellow?

Comment: Obviously, a double solid yellow line system is more expensive than a single line -- but only in paint cost which is considerably less than the labor and equipment costs associated with pavement marking. In reality, it costs only slightly more to paint two lines than one because the major expense is caused by labor and equipment costs and the striping machine must travel the street system to paint even the single line. Most situations do not dictate the double yellow level of control. The dashed yellow centerline would be appropriate in most situations and less costly.

Question 11. Will the public accept and understand a new untested concept of a single solid yellow center line?

Comment: Although extensively tested, the single solid yellow line has not demonstrated any substantial advantage over the dashed yellow line. Driver understanding of the legal intent is considerably less than what might be termed "criteria performance level," however, drivers appear to operate on urban streets marked with it essentially the same as they would on streets marked with dashed yellow -- they view it as a lane demarcation system.

Question 12: Is the Traffic Engineer confronted with a condition without an appropriate method of handling?

Comment: The experience of the seven years since adoption of the current MUTCD indicates that this anticipated problem failed to materialize. The system of markings provided by the MUTCD has proven adequate to meet the needs.

ENFORCEMENT POLICY OF THE SINGLE SOLID YELLOW CENTERLINE IN URBAN AREAS

Supervising police officers in Charleston, South Carolina and Cedar Rapids, Iowa were interviewed to determine enforcement policy and problems (if any) associated with the single solid yellow centerline marking in these two cities.

Police in both cities stated that the key issue in enforcement must be application of sound common sense. For example, when a stopped vehicle blocks the travel lane, it is unreasonable to expect drivers to wait unnecessarily in queue. Crossing the centerline to pass a stopped vehicle would not result in a citation if it was accomplished safely with due regard for the opposing traffic or pedestrians. Conversely, a citation would be issued in Charleston if the passing maneuver was accomplished in the absence of some unusual circumstance or was basically unsafe in the opinion of the police officer -- in Charleston passing across the single solid line is legally prohibited; hence a citation for improper passing is legally acceptable. In Cedar Rapids, since the legal interpretation of the single solid yellow line is one that permits passing (attempts to discourage it but nevertheless permits it), a citation cannot be issued for improper passing with respect to the marking; it must be issued for another offense such as traveling-to-left-of-centerline. Traffic laws currently are in existence nationwide regarding unsafe traveling on the opposing lane, however, and most drivers are cognizant of the potential hazard and legality of such action.

Charleston police stated that citations were more common with the single solid yellow line than with the double yellow marking. Double yellow line violations were considered to be very infrequent -- usually involving deliberate crossing of the double line to pass a slow-moving vehicle. In Charleston, no court cases were known to have been dismissed because the single solid yellow line is a non-standard marking. The one problem cited involved transition from one-way to two-way operation. Out-of-state drivers were sometimes confused by the single solid yellow line and drove on the wrong side of the roadway. Charleston police stated that the only change in either state law or city ordinance that would enhance enforcement of the single solid yellow line would be a more specific wording regarding no-passing; however, they maintained that responsible enforcement overcame most legal deficiencies.

DRIVER INTERPRETATION OF MARKINGS AND SIGNS

As was expected, drivers demonstrated a high level of understanding of intent of the single dashed centerline, the single dashed centerline in conjunction with a solid line (conventional no-passing zone marking), and the double solid yellow line system (conventional no-passing zone in both travel directions) both in the urban and rural environment. The understanding of the intent of the single solid yellow line, however, was quite varied in both the urban and the rural situation with respect to passing legality. Drivers recognized that crossing any pavement centerline marking to turn left into a driveway entrance or minor roadway generally was permissible. The findings with respect to driver understanding of each of the above marking systems are discussed in the following paragraphs.

Single Solid Yellow Centerline

Question number 1 in all four regional studies was designed to elicit subject interpretation of the single solid centerline with absolutely no biasing instructions that the study involved the passing maneuver. Of particular interest were the frequency of responses that mentioned passing or no-passing. In Charleston, it is legal to turn across the marking but illegal to pass; in Cedar Rapids, it is legal to turn across and to pass where the single solid centerline is used. Correct interpretations by subjects are summarized in Table 30.

Charleston drivers, in Study 1 regarding the legal intent of the urban centerline marking, apparently were quite cognizant that the single solid yellow line denoted "no-passing." Whether this can be attributed to comprehensive driver education or the fact that Charleston employs single dashed yellow and reserves single solid yellow for narrow urban streets primarily in the business area of the city is not known; however, 67 percent of the subject drivers stated that the single solid yellow line meant "no-passing" permitted with no biasing instructions. Cedar Rapids drivers exhibited a lesser understanding, only 24 percent stating correctly that passing was permitted. It is possible that, although enforcement practice permits passing with care, the subject drivers equate the solid yellow line with passing prohibition as they do in the rural environment. When presented the single solid yellow centerline marking in the rural environment with no biasing instructions in Study 4, 41 percent of the Cedar Rapids subjects believed that passing would be permissible with such a marking system. No apparent reason for this difference could be deduced.

When asked specifically if passing was or was not permitted across the single solid yellow centerline, the responses were somewhat different as shown in Table 31.

TABLE 30

CORRECT INTERPRETATION OF INTENT OF SINGLE SOLID YELLOW CENTERLINE

Study Number	Number of Correct Responses	Sample Size	Percent Correct	Environment	Reference Source (Ref. 61)
1	31	46	67	Urban	Table E-2
2	6	29	24	Urban	Table E-20
3	9	34		Urban	Table F-2
4	16	39	41	Rural	Table G-2

TABLE 31

CORRECT INTERPRETATION OF SINGLE SOLID YELLOW CENTERLINE WHEN ASKED SPECIFICALLY IF PASSING IS ALLOWED

Study Number	Number of Correct Responses	Sample Size	Percent Correct	Environment	Reference Source (Ref. 61)
1	24	47	51	Urban	Table E-5
2	18	29	51	Urban	Table E-23
3	14	34		Urban	Table F-4
1	19	47	40	Rural	Table E-12
2	18	29	54	Rural	Table E-30
4	19	39		Rural	Table G-4

When presented the operational situation of trailing a very slow moving vehicle, approximately half the subject drivers in both Charleston and Cedar Rapids believed that it would be legal to pass the vehicle across the marking in either the urban or the rural environment. It is not known if the operational situation biased the subjects' decision more than the marking system. Even when the situation involved a stopped vehicle, (61, Tables E-7 and E-25), only 48 percent and 62 percent respectively of Charleston and Cedar Rapids drivers correctly stated that the stopped vehicle could be passed legally, yet a stopped vehicle blocking a lane may be passed across marking if it does not interfere with other traffic.

As indicated in Table 32, an average of 77 percent of the subject drivers believed correctly that a left turn may be legally made across the single solid yellow centerline on an urban street, and 87 percent believed it to be legal on a rural highway.

Other Conventional Centerline Markings

Tables 33, 34, and 35 indicate that the subject drivers exhibited a high level of understanding of the legal intent with respect to passing across a single dashed yellow centerline, a double solid yellow centerline and a conventional one directional no-passing zone centerline marking.

Differences Between Single Solid Yellow Centerline and Conventional Markings

It is recognized that drivers were naive regarding the intended meaning of a single solid yellow centerline on a rural highway (it is not used appreciably). To further identify differences in interpretation among markings, drivers in Charleston and Cedar Rapids were asked to state if selected conventional markings conveyed the same legal meaning as the single solid yellow line or if they conveyed a different meaning with respect to passing in an urban or a rural environment. The single solid yellow line meaning was compared to a single dashed yellow line and a double solid yellow line, both of which are well understood and both of which can be found in an urban and a rural environment. The data are summarized in Table 36.

TABLE 32 CORRECT INTERPRETATION WITH RESPECT TO TURNING LEFT ACROSS SINGLE SOLID YELLOW CENTERLINE

Study Number	Number of Correct Responses	Sample Size	Percent Correct	Environment	Reference Source (Ref. 61)
1	35	47	74	Urban	Table E-10
2	26	39	67	Urban	Table E-28
3	31	34	91	Urban	Table F-3
4	34	39	87	Rural	Table G-3

TABLE 33 CORRECT INTERPRETATION OF SINGLE DASHED YELLOW CENTERLINE WITH RESPECT TO PASSING

Study Number	Number of Correct Responses	Sample Size	Percent Correct	Environment	Reference Source (Ref. 61)
3	32	34	94	Urban	Table F-2
4	35	39	90	Rural	Table G-2
3	33	34	97	Urban	Table F-4
4	38	39	97	Rural	Table G-4

TABLE 34 CORRECT INTERPRETATION OF DOUBLE SOLID YELLOW CENTERLINE WITH RESPECT TO PASSING

Study Number	Number of Correct Responses	Sample Size	Percent Correct	Environment	Reference Source (Ref. 61)
3	34	34	100	Urban	Table F-2
4	38	39	97	Rural	Table G-2
3	34	34	100	Urban	Table F-4
4	36	39	92	Rural	Table G-4

TABLE 35 CORRECT INTERPRETATION OF CONVENTIONAL ONE DIRECTIONAL NO-PASSING ZONE MARKING

Study Number	Number of Correct Responses	Sample Size	Percent Correct	Environment	Reference Source (Ref. 61)
4	37	39	95	Rural	G-2
4	33	39	85	Rural	G-4

TABLE 36 COMPARISON OF MEANING OF SINGLE SOLID YELLOW LINE TO OTHER MARKINGS ON URBAN AND RURAL ROADWAYS

Marking System	Rural Highway		Urban Street	
	Same Meaning	Different Meaning	Same Meaning	Different Meaning
Dashed Yellow				
Study 1	15	32	21	26
Study 2	14	15	16	13
Double Solid Yellow				
Study 1	27	19	30	16
Study 2	13	16	13	16

Note: 1) Study 1, N=47, Reference Tables E-14 and E-15. (61)
2) Study 2, N=29, Reference Tables E-32 and E-33. (61)

The intent of the single solid line is that it represents a compromise between the driver's understanding of a "passing" zone and a "no-passing" zone on the rural highway. Therefore, it should not convey the same meaning as either the dashed yellow line or the double solid yellow line, yet 38 percent of all subjects believed the single solid line meant the same thing as the dashed line and 53 percent believed it to be equivalent to the double solid line on rural highways.

The double solid yellow line conveys no-passing to almost all drivers whether used in the urban or rural environment (Reference Table 34). Nearly 57 percent of the subject drivers stated that the single solid yellow line was equivalent to the double solid yellow line on an urban street. If the intent of the single solid yellow line is to convey "no-passing," its use in this context could be expected to be understood by only about half the drivers. The other half interpret it differently, and from comparison of the single solid yellow line to the dashed yellow (a system conveying "passing" to most drivers) it appears that 51 percent of the drivers from the two cities (where the meanings are opposite) believe the single solid yellow line to be analogous to the dashed yellow centerline on an urban street.

Summary of Driver Understanding of Marking Systems

The studies indicated a high level of understanding for the dashed yellow line, the conventional unidirectional no-passing dashed/solid combination, and the double yellow. The single solid yellow line was not understood at levels even approaching what might be considered criteria performance (usually at least 85 percent performance). The underlying interpretation throughout the studies was that there is some unknown difference between the single solid yellow line and either the dashed yellow line or the double solid yellow line, but the overall interpretation is that it prohibits legal passing -- analogous to the solid yellow alongside the dashed centerline or the double solid yellow line system. Since its intent is not to absolutely prohibit passing, but to convey that passing may be accomplished under unusual conditions, it appears that extensive education would be necessary to produce high understanding levels. Other systems of denoting restrictive passing should be investigated before consideration is given to widespread implementation of the single solid yellow centerline.

DRIVER UNDERSTANDING OF SIGNING SYSTEMS

Several signing techniques were investigated to determine the feasibility of denoting restrictive passing zones on rural highways through the use of signs alone or in conjunction with pavement markings. Drivers were asked to evaluate signs displaying passing information with and without specific speed information and to select preferred shapes on which to display restrictive passing zone information. In addition, drivers were asked to define a "slow vehicle" in terms of its possible usage in lieu of specific speed information. The results of the sign studies are discussed individually below.

Driver Definition of a "Slow Vehicle"

One method considered to convey that only very slow-moving vehicles were to be passed where the single solid yellow line was used involved displaying a specified speed value on a sign with verbal message stating that only vehicles traveling less than the specified speed should be passed, others traveling faster should not be passed. Presentation of such a message produces long sign messages; therefore, drivers were asked to quantify the word "slow-vehicle." If a high percentage defined "slow" to be within a narrow speed range, it was considered possible that this type of wording could replace the lengthy message.

Drivers were asked to specify a 10-mph (16.09 km/h) range which best described the speed of a "slow vehicle." The subject responses are presented in Table 37 for all studies. More than 80 percent of the subjects (83.9 percent) defined a "slow vehicle" to be one traveling between 10 mph (16.09 km/h) and 40 mph (64.37 km/h) with the responses being about equally distributed for each 10-mph (16.09 km/h) increment within this 30 mph (48.28 km/h) range.

The diversity in opinion of "slow" indicates that, if an acceptable level of driver understanding of allowable operating conditions is to be acheived, discrete speed values must be displayed. The fact that almost 30 percent of the drivers defined a slow vehicle speed to be between 30 and 40 mph (48.28 and 64.37 km/h) indicates that the concept of restrictive marking is potentially more hazardous than originally assumed because this speed is only slightly less than normally expected operating speeds on heavily rolling terrain and only 15 mph (24.14 km/h) less than the national 55 mph (88.51 km/h) maximum speed limit. Drivers may consider 40 mph (64.37 km/h) to be "slow," however, it is submitted that a high majority of them are not aware that at 40 mph (64.37 km/h), a passing vehicle travels almost 600 ft (183 m) during left lane occupancy alone and this distance does not include needed sight distance to perceive an opposing vehicle. Minimum suggested passing sight distance resulting from this study is 700 ft (213 m) for 40 mph (64.37 km/h) operating speeds.

TABLE 37 DEFINITION OF "SLOW VEHICLE"

Speed Range (mph)	Responses	
	Frequency	Percent
Less than 10 mph	7	4.7
Less than 20 mph	42	28.2
Less than 30 mph	40	26.8
Less than 40 mph	43	28.9
Less than 50 mph	17	11.4
Greater than 50 mph	0	0

Note: *(1) N = 149 (total sample size)*

(2) 1 mph = 1.609 km/h

(3) Reference Tables E-16, E-34, F-5, and G-5 (61)

Evaluation of Sign Messages Without Specified Speed Information

To further investigate the effectiveness of sign messages in conveying the intended meaning of "restricted passing" without specifying a maximum speed of vehicle that can be passed, drivers were asked to rank the five sign messages listed below:

1. Pass Only Slow Vehicles
2. Pass Slow Vehicles Only
3. Passing Slow Vehicles Permitted
4. Pass With Care
5. Slow Vehicle Passing Zone

The responses from the four studies are presented individually in Tables E-17, E-35, F-6, and G-6 in the appendices of Reference 61. Table 38 presents the aggregate responses for all subjects with preference rankings indicated.

TABLE 38

AGGREGATE DRIVER PREFERENCE OF SIGN MESSAGES WITHOUT SPECIFIED SPEED

Sign Messages	Frequency of Response Rankings						Ranking	Preference
	First	Second	Third	Fourth	Fifth	N		
Pass Only Slow Vehicles	15	26	32	39	27	139	454	4th
Pass Slow Vehicles Only	22	30	35	41	11	139	406	3rd
Passing Slow Vehicles Permitted	23	41	41	22	11	138	371	2nd
Pass With Care	36	10	7	11	79	143	516	5th
Slow Vehicle Passing Zone	48	35	22	25	11	141	339	1st

Notes: 1) *A low numerical ranking indicates a high preference; conversely, a high numerical final ranking indicates a low preference. Ranking equals the summation of frequency times numerical position.*

2) *N is the number of subjects who selected a particular sign message.*

SLOW VEHICLE PASSING ZONE was the message most preferred by the aggregate of the subjects and was the first choice of each individual set of subjects in Studies 2, 3, and 4 (ref. 61 Tables E-35, F-6, and G-6). It was the second choice of the Charleston subjects (ref. 61, Table E-17). PASS WITH CARE received the lowest ranking by all groups individually and collectively, possibly because this sign is used in several states at the downstream end of a no-passing zone to denote the start of a "passing" zone. Also, it was the only message that did not infer that passing was restricted to only "slow" vehicles. Apparently interpretation of PASS WITH CARE is that it is considered cautionary and some of the subject drivers interpreted it as conveying permissible open passing with sufficient sight distance for higher speed operation. Since this sign is, by color and shape, a regulatory sign, concern has been expressed by attorneys that it may be considered a carte blanche invitation to passing if contested in court; hence, the use of this sign appears to be declining even at zones where opposing vehicle criteria sight distance is available. PASSING SLOW VEHICLES PREMITTED individually and collectively represented the most feasible second choice of messages with the other three messages receiving rankings considerably lower (Table 38).

The concept of using the word "slow" to define acceptable operating conditions, however, does not appear to be feasible because of the wide diversity in driver interpretation of what constitutes a "slow" vehicle. Therefore, this type of information is not advocated.

Evaluation of Sign Messages With Specified Speed Information

It was considered highly probable that only the word "slow" would be inadequate to clearly define, to a passing driver, precisely which vehicles could be passed under the limited sight distance and which vehicles should not be passed. It was believed that, for reasons of driver understanding, and legal purposes, the decision should not be left to drivers; instead the specific allowable passing conditions should be clearly defined with respect to maximum speed of the vehicle to be passed. Four possible sign messages were selected that specified the maximum speed of a vehicle that could be passed legally within the uniquely marked restrictive passing zone. Sign messages displaying the wording to convey this type of information are necessarily lengthy because the vehicle to which the speed applies can be ambiguous. For example, does, "vehicle-less-than" pertain to the passing vehicle or the passed vehicle? Therefore, the messages were developed to specify, as clearly as possible, that the speed information referred to the vehicle that was to be passed, not to the speed of the passing vehicle during the passing maneuver. Drivers were asked to preference-rank the four sign messages listed below with respect to the capability of the message to provide this type of information:

1. Pass Only Vehicles Traveling Less Than XX Mph
2. Do Not Pass Vehicles Traveling More Than XX Mph
3. Do Not Pass Vehicles Traveling Faster Than XX Mph
4. Limited Sight Distance -- Pass Only Vehicles Less Than XX Mph

The responses from the four individual study sets are presented individually in Tables E-18, E-36, F-7, and G-7 of Reference 61. Table 39 presents the aggregate responses for all subjects with preference rankings indicated.

The message LIMITED SIGHT DISTANCE -- PASS ONLY VEHICLES LESS THAN XX MPH was the first choice of all subjects individually and collectively. Similarly, PASS ONLY VEHICLES TRAVELING LESS THAN XX MPH was the second choice. The remaining two messages received third and fourth preference rankings with almost equal numerical rankings.

Messages No. 1 and 4 present information in a positive manner whereas messages 2 and 3 present negative information. Message 4, in addition to eliciting positive response, presents the reason for the desired action in terms that drivers apparently understand and can equate to potential hazard--"limited sight distance."

Sign Shape Preference Studies

The concept of restrictive passing is unique to driver expectancy; hence, it was believed that the shape of the sign blank might be considered desirable by drivers. Drivers were asked to rate three sign shapes in a "best" and "worst" category; the objective being to determine if a unique shape was considered desirable in displaying the information regarding the allowable

TABLE 39

AGGREGATE DRIVER PREFERENCE OF SIGN MESSAGES WITH SPECIFIED SPEED

Sign Message	Frequency of Response Rankings					Ranking	Preference
	First	Second	Third	Fourth	N		
Pass Only Vehicles Traveling Less Than XX Mph	39	50	22	30	141	325	2nd
Do Not Pass Vehicles Traveling More Than XX Mph	10	31	60	36	137	396	4th
Do Not Pass Vehicles Traveling Faster Than XX Mph	12	39	47	40	138	391	3rd
Limited Sight Distance... Pass Only Vehicles Less Than XX Mph	81	20	8	33	142	277	1st

Note: 1) *A low numerical ranking indicates a high preference; conversely, a high numerical final ranking indicates a low preference. Ranking equals the summation of frequency times numerical position.*

2) *N is the number of subjects who selected a particular sign message.*

operating conditions in a restrictive passing zone.

The subjects also were asked to state reasons for their choices. Tables E-19, E-37, F-8, and G-8 of Reference 61 present the results of the individual study sets. Table 40 presents an aggregate of responses for all subjects combined. As indicated in Table 40, the aggregate shape ratings indicated almost total randomness in preference. The unique hour-glass shape received more favorable response (the highest frequency of "best" ratings combined with the lowest frequency of "worst" ratings, ref. 61, Tables F-8 and G-8) by the Cedar Rapids drivers in Studies 3 and 4. The most frequently stated reason for selecting it was that it was not used for any other existing sign message whereas the diamond shape was common and the triangle resembled the YIELD sign or the NO PASSING ZONE pennant to many subjects.

The diamond and the triangle were preferred respectively by Charleston drivers and Cedar Rapids drivers in studies 1 and 2. The shape of any sign used must be one that will provide sufficient space for the lengthy messages believed necessary. Also, if the message was of a regulatory classification as opposed to a warning classification, the shape probably would be dictated by the uniformity rules for sign shape now in current usage.

TABLE 40

AGGREGATE DRIVER PREFERENCE FOR SIGN SHAPE

Sign Shape	Frequency of Responses for Each Category	
	Best	Worst
Hour Glass	72	59
Diamond	41	48
Triangle	35	39
	N=148	N=146

Note: N is the number of subjects who selected a particular sign message.

THE RESTRICTIVE PASSING CONCEPTS AS VIEWED BY ENFORCEMENT PERSONNEL

The concept of restrictive passing application and demarcation was discussed with State Police personnel from four States in a two-day workshop (19). Opinions of its attributes and faults were solicited with regard to driver safety, enforcement and the effect it might have on conventional no-passing zone compliance. In addition to the comments received from the police in attendance, follow-up interviews were held with police personnel from ten other States.

The consensus of enforcement personnel with mainly rural highway responsibilities was that a system of uniquely designated restrictive passing zones should not be included in any recommendations for changes in national standards. The significant items of discussion are summarized.

Safety

> *The conceptual intent of restrictive passing zones, as discussed at the workshop, is to relieve unnecessary vehicular bottlenecks on highway sections where sight distances are not sufficient for standard passing zones, and where traffic operations are often substantially different than normal conditions assumed for the determination of passing and no-passing zones. Although a driver could not safely pass in a normal situation, he could make an exception and exercise his judgement to pass in certain circumstances (such as a very slow truck on a long grade) where the required passing distance is less than required for normal passing situations (19).*

The police believed that the major problem would occur in conveying to the driver precisely what constituted a permissible situation. They believed that an unsafe situation would be created when a driver exercised poor judgment and attempted to execute a passing maneuver in a situation that did not meet the "exceptional circumstance" criteria.

Enforcement

State Police stated that they believed the restrictive passing zone would increase the judgment factor to be exercised by the driver. Enforcement, therefore, would be predicated on driver judgment and not on law or regulation. Thus, definition of enforcement policy would be extremely difficult if not impossible. Police believed that the concept could be enforced only when an accident occurred.

Effect on No-Passing Zone Compliance

Enforcement personnel believed strongly that the existing meaning of a solid yellow line, well recognized by the public as a passing prohibition device, would be severely impaired by usage of a single solid yellow line for designation of restrictive passing zones. The opinion was expressed that a uniquely designated restrictive passing zone would be confusing to the average driver.

CHAPTER 16

RESEARCH RESULTS AND CONCLUSIONS

A decision regarding nationwide usage of a restrictive passing marking/signing system of traffic control devices cannot be substantiated on the limited study conducted herein; development of criteria and warrants for such a system would entail a comprehensive and detailed study in itself. The intent of this phase of the research reported here was to investigate the feasibility of using the single solid yellow line for this purpose because the current MUTCD did not contain provision for the solid yellow line centerline whereas the preceding MUTCD had sanctioned a solid white centerline.

The conclusions and suggestions presented here are based solely on the findings from the accident comparison, driver understanding studies and discussions with traffic engineers, lawyers, and enforcement personnel at the workshops. The four questions presented in Chapter 14 are addressed separately below with respect to the capability of the single solid yellow centerline in representing an acceptable solution to the question.

IS THERE A NEED FOR RESTRICTIVE PASSING ZONE MARKING?

Rolling and mountainous terrain imposes a substantial problem to providing roadway profiles that permit adequate minimum passing sight distance. Traffic engineers are faced with a dilemma. They fully recognize the safety requirements on which minimum passing sight distance criteria are based and in general believe in the concept of applying traffic control devices in a uniform basis to provide necessary safety for the motoring public for professional as well as legal reasons. On the other hand, those whose responsibility includes operating roadways in mountainous terrain are faced with the problem of attempting to provide as much roadway that is not marked for prohibitive passing as is possible on roadways that cannot, under accepted definitions of "safety," legally provide passing opportunity. Yet, the driving public in these areas, according to opinions expressed at the review workshop (53), demand that they not be denied the potential to pass slow-moving vehicles. The fact remains, that if minimum passing sight distance is defined as the actual sight distance to provide completion of the passing maneuver without risking conflict with an opposing vehicle; then allowing passing where sight distance is less than this value is in effect, trading "safety" for convenience.

The question appears to be mis-stated. If it were stated, "is there a need to provide safe passing opportunity on mountainous roadways?" the question could probably be answered affirmatively. Since information could not be offered regarding the criteria on which proponents of the restrictive marking system based their definition of "need," it was not determined that an actual "need" to permit restricted passing existed. When questioned regarding observed traffic queues, delays, and accident rates on roadways on which the restrictive marking might be considered, the information was not readily available; however, it was expressed that accident rates were not believed to be unusually high at those locations where restrictive markings (or no markings) were being used or had been used in mountainous areas.

The identification of "need" may be produced by an ongoing field study of the single solid yellow centerline being conducted in Virginia (59). At this time, it is submitted that a need to provide passing opportunity exists; however the demonstrated misunderstanding of the single solid yellow intent, the legal ramifications that might arise, the expected driver disrespect for the solid yellow line in general, and the philosophy of allowing drivers the legal right to decide when a control device applies, indicate that the single solid yellow line for this usage does not provide an acceptable solution.

Accident comparison rates between urban streets marked with dashed and solid yellow centerline did not reflect significant differences. Drivers indicated that passing was not considered to be a problem in urban areas; therefore, it appears that, on urban streets, the use of a single solid yellow line is not needed if its sole purpose is to denote passing restriction. From an economic aspect, the dashed yellow centerline would be less costly and from this viewpoint, use of the solid line marking might be considered undesirable with respect to conservation of materials.

CAN A MARKING BE DEVISED?

Results of the driver understanding studies of the single solid yellow line for restrictive marking on rural highways indicate that this system does not display adequate information (even with the supplementary signing studied) to the driver regarding the specific conditions under which passing should be attempted. Other techniques may provide the needed information; however, it is believed strongly at this time that the system will require signing rather than (or in conjunction with) merely pavement marking. The system used in Virginia (reference Chapter 8) in which pavement markings are omitted throughout the mountainous roadway and cautionary signing is displayed at frequent intervals throughout the unmarked roadway may represent a technique that would alleviate the opposing intents for the solid yellow line. The sign, DO NOT PASS WHEN SOLID LINE IS ON YOUR SIDE, is placed at the end of the mountainous roadway and barrier stripes are used. This system exhibits one apparent deficiency in that no centerline marking is present to provide roadway guidance in an environment where guidance is important to proper vehicle/lane position. It does not, however, necessitate a double standard for the single solid line. The legal ramifications have not been tested in court so far as is known. However, it is possible that a marking could be devised that does not contain the solid yellow line to be used in conjunction with the cautionary signing so that the total system would convey only one intent. It is strongly suggested that if any unique control device system is developed to permit legal passing operations where minimum passing sight distance is less than the values suggested in Part I of this report, the criteria and warrants for its usage specify applicable roadway conditions to avoid the possibility of widespread usage merely for convenience.

WHAT IS THE EFFECT OF USING SUCH A MARKING?

Single Solid Yellow Line Usage on Urban Streets

From an operational aspect, the single solid yellow centerline on narrow urban two-way two-lane streets exhibits no appreciable advantage over the conventionally used dashed yellow centerline. Conversely, its use does not exhibit any operational disadvantage. The solid yellow line alone or in combination with dashed or solid longitudinal yellow lines conveys to drivers the intent of "prohibition to crossing for passing" in general; however, if the single solid yellow line is used, education of the driving public is considered necessary to define the legal intent because the understanding level is considerably lower than that of the double yellow line system or the dashed/solid combination. The legal intent of the single solid yellow line should be uniformly established to denote prohibitive passing under normal operating situations and the marking system applied where this represents the desired operational intent.

If used, the single solid yellow line should be reserved for application on narrow urban streets where pavement width would be seriously reduced by normal centerline width. It should not be used as a centerline marking on four-lane urban streets.

The dashed yellow centerline is considered equally effective in most cases and represents a more economical marking system with respect to conserving marking material.

Single Solid Yellow Line Usage on Rural Highways

Current warrants for designating no-passing zones are inadequate for safe completion of a passing maneuver, yet the roadways on which use of the restrictive passing zones would be anticipated contain numerous no-passing zones even under these warrants, and even though they generally are marked for reduced operating speeds. The philosophy of restrictive passing places the complete decision burden on the passing driver whereas numerous driver studies have indicated that, even under relatively good sight distance conditions, drivers lack the capability to accurately judge distance, speed, and their interrelationship during the passing maneuver. It is a well accepted premise that basic design inadequacies cannot be effectively remedied by use of the traffic control devices. The concept of restrictive passing represents an attempt to alleviate an operational condition that is a direct result of inadequate design for desired operations through use of traffic control devices with the trade-off being severely reduced driver safety and possible concomitant liability allegations against the responsible agency. These considerations must be evaluated in determining the advantages or disadvantages of using the system.

There are specific areas along a roadway in rolling or mountainous terrain where absolutely no passing can be accomplished safely regardless of the vehicle speeds involved (such as near the crest of a vertical curve). Thus, the concept of restrictive passing in reality must become a mixture of borderline safety and prohibitive passing. To provide necessary safety for opposing drivers in the event a passing driver exercised poor judgment at one of these critical areas, the no-passing zones must be clearly designated. This would entail double signing or double marking systems. Double signing would be undesirably costly; double marking would involve solid yellow barrier striping in conjunction with centerline marking to denote applicable travel direction. The use of the solid yellow line for both demarcation systems would produce conflicting meanings for the same control device.

The research results concerning passing/no-passing zone establishment indicated that drivers should be advised through markings and/or signs where passing was prohibited based on needed sight distance for safe completion of the maneuver. When geometric constraints preclude provision of adequate passing sight distance along the travel lane for extended lengths of roadway, it is believed that provision of safe passing opportunity at frequent intervals with perhaps signing to advise drivers that passing opportunity exists represents the better approach to alleviating delays associated with slow moving vehicles. These passing opportunities can be provided by incorporation of additional passing lanes, shoulders, turn-outs, or other geometric features.

CAN DRIVERS ACCURATELY INTERPRET THE MEANING OF SUCH A MARKING?

The studies indicated a high level of understanding for the dashed yellow line, the conventional unidirectional no-passing dashed/solid combination, and the double yellow. The single solid yellow line was not understood at levels even approaching acceptable criteria performance. The underlying interpretation throughout the studies was that there is some unknown difference between single solid yellow and either dashed yellow or double solid yellow, but the overall interpretation is that it prohibits legal passing -- analogous to the solid yellow alongside the centerline. Since the longitudinal solid yellow line connotes this, it is strongly believed that its use should be restricted solely for this intent and should not be subgraded to a "sometimes/ sometimes not" intent. Such a conflicting intent could produce serious driver confusion and create hazardous operations on rural highways if the driver misinterpreted the intended meaning at an inopportune situation where opposing vehicles could not avoid conflict. The ramifications of misunderstanding the intent in the urban environment on narrow streets are appreciably less severe because the expected speeds are lower and the driver expectancy is considerably different.

CONCLUSIONS

The concept of designating restrictive passing zones is in direct opposition to driver understanding and expectancy in the use of longitudinal markings or signs to denote those locations where driving to the left of the centerline is potentially hazardous. Drivers understand and accept the conventional philosophy of being advised when passing is specifically prohibited; in fact during this study, drivers stated that they preferred that borderline "passing" zones be closed up to designate no-passing if there was insufficient length to complete the maneuver without encroaching the downstream no-passing zone (Ref. 61).

Since the concept of restrictive passing is so diametrically opposed to the concept of individual passing or no-passing zones, it is proposed that a completely unique marking and/or signing system be considered if restrictive passing zones are to be considered. Based on the results of this research study, the following proposals are offered regarding the use of the single solid yellow centerline:

1. The use of the single solid yellow centerline on narrow two-lane two-way urban streets should be allowed, but not encouraged as national policy. If it is used, uniform intent, application and enforcement should be adopted -- passing not permitted under normal expected traffic conditions.
2. The concept of allowing restrictive passing and providing demarcation on rural highways to convey singular unambiguous meaning should be studied further to identify a true need and to evaluate the capability of other traffic control devices to provide the necessary information.

Based on this study of only the one system -- the single solid line -- the single solid yellow line should not be used to convey the desired intent because the driver understanding level demonstrated was too low.

The decision to permit restrictive passing should be postponed at least until the results of the on-going Virginia study (59) are made available. The driver understanding level demonstrated may be considerably higher because the marking system will be experienced by drivers who are familiar with the mountainous driving environment.

3. The use of the solid yellow line on rural two-lane roadways should be restricted to the sole purpose to which the majority of drivers ascribe its use -- designation of lengths of roadway in which passing is legally prohibited. Drivers in general interpret the solid yellow line as "prohibitive" and it is strongly believed that this single meaning should be maintained. The left edge line on a divided highway would then represent the only other usage of the solid yellow line and it is believed that although this usage is consistent with travel direction denoted by yellow line color, most drivers do not recognize it as meaning this; they treat it the same as a white edge line. The median itself conveys travel direction to them through physical separation of the sets of travel lanes.

APPENDIX --REFERENCES AND ANNOTATIONS

The study encompassed many separate, but related elements of consideration in developing criteria, warrants, and traffic control devices for establishment of safe passing and no-passing zones on rural two-lane highways. Since the research was to be conducted making maximum utilization of previous research, it was considered essential that an extensive literature review be made to identify the current state-of-the-art in passing-related research and practice.

Literature pertaining to the passing maneuver was reviewed to identify vehicle performance characteristics, driver and roadway characteristics, accident statistics, criteria development, legislation, current practice, and cost information as related to the passing maneuver. The literature sources exhibiting direct application to the concepts developed in this research are listed numerically herein with annotations describing the information and its relevancy to this research effort. In cases where the literature sources are cited to support generalized statements within the text of the report, the source is only briefly annotated. Where numerical data from previous research are used to develop criteria or warrants, a more extensive annotation is presented to provide the reader a basis for evaluation of the resulting usage. Similar reference sources from which various vehicle performance characteristics were obtained are annotated collectively.

ANNOTATED REFERENCES

1. Gordon, Donald A. "Studies of the Road Marking Code." FHWA-RD-76-59, April 1976.

   Gordon's study indicated that drivers understood well the intent of the single dashed centerline and the solid line as denoting permission or prohibition to cross respectively. Also, yellow markings were associated with hazard. The markings best understood by subjects were those closely related to passing. These findings added considerable credence to the development of advance treatments making maximum usage of the dashed and solid line adjacent to the roadway centerline because this marking philosophy appears to be logical and understandable to drivers.

2. Van Valkenburg, G. W. "No-Passing Zones: Criteria, Legislation and Location." Final Report, Project No. C-36-17FF, Purdue University, June 1969.

   Van Valkenburg's study represents one of the primary defending cases for use of the long zone concept in marking no-passing zones. The minimum passing sight distances suggested in the study reflect larger values than does the MUTCD (reference Table 8, herein) but shorter values than suggested herein. The advance treatment concept developed herein represents a compromise but without denoting prohibitive passing (to most drivers) through use of a solid yellow line. The long zone criteria add credence to the resulting warrants developed in this study.

3. Manual on Uniform Traffic Control Devices for Streets and Highways. U.S. Department of Commerce. Washington, D.C., 1971.

   The document represents the accepted national standard for establishing and marking/signing no-passing zones. As such, the criteria on which the warrants are developed represent the basis to which the safety aspects of the passing maneuver are compared.

4. Silver, C., and E. Farber. "Conceptualization of Overtaking and Passing on Two-Lane Rural Roads." Franklin Institute Research Laboratories Technical Report 1-193. March 1969.

5. Gordon, Donald A. and Truman M. Mast. "Driver's Decisions in Overtaking and Passing." HRR No. 247, 1968.

6. Jones, Howard V. and Norman W. Heimstra. "Ability of Drivers to Make Critical Passing Judgments." HRR No. 122, 1966.

7. Farber, Eugene and Carl A. Silver. "Behavior of Drivers Performing a Flying Pass." HRR No. 247, 1968.

8. Silver, Carl A. and Eugene Farber. "Driver Judgment in Overtaking Situations." HRR No. 247, 1968.

9. Farber, Eugene and Carl A. Silver. "Knowledge of Closing Rate Versus Knowledge of Oncoming-Car Speed as Determiners of Driver Passing Behavior." HRR No. 247, 1968.

The above six research studies collectively indicate that drivers generally are inept in correctly judging such variables in the passing maneuver as oncoming vehicle speeds, closing rate, passing distance, clearance time, and the last point at which a passing maneuver can be safely executed. The studies, conducted through controlled experiments with subject drivers for the most part, infer that the driver workload during this complex maneuver may be approaching threshold limits and suggest that additional information sources will improve the driver's ability to execute a safer passing maneuver. The findings and conclusions of these studies support the assumed desirability of advance notification of the downstream end of the passing zone and provision of traffic control devices that are visible at the position in the maneuver where the decision to abort or complete the pass is made.

10. Normann, O. K. "Progress in Study of Motor Vehicle Passing Practices." HRB Proc., Vol. 19, 1939.

11. Prisk, C. W. "Passing Practices on Rural Highways." HRB Proc., Vol. 21, 1941.

The passing maneuver measurements by Normann and Prisk, nearly 40 years ago, constitute the basis for passing distance elements used currently to establish criteria for design and marking practice. The findings regarding vehicle acceleration rates and vehicle relative position throughout the maneuver appear to be generally valid for modern vehicle operation when evaluated against similar maneuver measurements obtained within the last decade.

12. "Performance Data for New Passenger Cars and Motorcycles." Consumer Information Series, U.S. Department of Transportation, National Highway Safety Bureau, Annual Publications.

The Consumer Information Series contain vehicle acceleration and passing ability of passenger automobiles as measured in accordance with the federally specified test situation described. Data are compiled for all passenger automobiles concerning passing times and distances for "low-speed" and "high-speed" passes. The low-speed test assumes an initial speed of 20 mph (32.2 km/h) and a limiting speed of 35 mph (56.3 km/h). The high-speed pass assumes an initial speed of 50 mph (80.5 km/h) and a limiting speed of 80 mph (128.7 km/h). The tests involve passing a 55-ft (16.8 m) truck traveling at 20 mph (32.2 km/h) or 50 mph (80.5 km/h) respectively. In the low-speed pass, the passing vehicle starts in the left lane 40 ft (12.2 m) behind the truck and completes the maneuver when it is 40 ft (12.2 m) ahead of the truck (clear distance in both positions). The high-speed pass involves the distance from 100 ft (30.5 m) behind the truck to 100 ft (30.5 m) ahead. The two vehicles remain in adjacent lanes throughout the maneuver.

13. Weaver, G. D., and John C. Glennon. "Passing Performance Measurements Related to Sight Distance Design," Report 134-6, Texas Transportation Institute, July 1971.

The study concerned examination of passing behavior on rural two-lane highways through high-speed movie filming of approximately 500 completed passing maneuvers at speeds from 50 mph (80.5 km/h) to 70 mph (112.7 km/h). Several thousand partially completed maneuvers were filmed. Vehicle relative positions, speed differentials, distance traveled for each element of the passing maneuver, lane position, acceleration, and other operational variables were determined from analysis of the movie film using a motion analyzer. Distance elements for the speed range studied were defined in terms of regression equations. These data were compared to previous vehicle measurements which formed the basis of the AASHTO passing distance criteria. The Weaver and Glennon data, although not appreciably different than the AASHTO design total distance values, are used in this research study merely because they represent more current data regarding modern vehicles.

14. Lee, C. E. "Driver Eye Height and Related Highway Design Features." HRB Proc., Vol. 39, pp. 46-60, January 1960.

15. Stonex, K. A. "Review of Vehicle Dimensions and Performance Characteristics." HRB Proc., Vol. 39, pp. 467-478, 1960.

16. "A Literature Review of the Research Done on Eye Height Dimensions of Passenger Vehicles." Urban Behaviorial Research Associates, Inc., November 1976 (unpublished).

17. "Present Trends in Driver Eye Height as Related to Passenger Vehicle Size." Michigan Department of Highways, Traffic Research Section, 1965.

Driver eye height is of critical concern in developing passing and no-passing criteria and warrants. The above studies document the decreasing driver eye height from 1936 to the present. Stonex's study provides historical trend data from 1936 to 1960 with findings that the median driver eye height decreased from 56.4 inches (1.4 m) in 1936 to 47.5 inches (1.2 m) in 1959. Lee's study based on photographic measurements of passenger cars in operation, indicated that 85 percent of measured eye height were greater than 3.95 ft (1.2 m). Lee recommended 3.95 ft (1.2 m) for design purposes. The UBRA study, using measurements of operating vehicles, suggests 3.5 ft (1.07 m) as representative of modern vehicle driver eye heights. It was specifically requested in the research study herein that use be made of the findings of the UBRA study. The 3.5-ft eye height (1.07 m) is proposed for design and marking purposes.

18. Alexander, Gerson J. and Harold Lunenfeld. "Positive Guidance in Traffic Control." U.S. Government Printing Office Stock No. 050-001-00094, FHWA, April 1975.

Alexander and Lunenfeld state that "information handling that leads to successful performance depends on the driver's ability to detect a hazard, recognize it as such, decide on an appropriate speed and path, and act on the speed and path decision. Positive guidance requires that the driver be given all the information needed to make the correct decision." They further state that, "detecting a hazard depends on how visible, conspicuous, and important it is, as well as the number of competing information sources." The concept of advance warning or "expectancy conditioning" the driver to the fact that a no-passing zone is being approached is believed to be in close association with the goals of positive guidance.

19. "No-Passing Zone Enforcement Practices and Problems Workshop." Washington, D.C., May 1977. Workshop held by Highway Users Federation for Safety and Mobility. Rankin, Woodrow, W. and Sonsteby, Ornulv, moderators.

A two-day workshop with attendees composed of FHWA research staff, the research principal investigator, enforcement personnel from five States, attorneys, traffic engineers from three States, and engineers from the Highway Users Federation for Safety and Mobility was convened to discuss enforcement policies and problems relative to enforcement of current no-passing zone traffic control devices. The consensus was unanimous among the enforcement personnel that better advance visibility of the start of a no-passing zone would be the most important improvement that could be made in the current method of designating no-passing zones.

20. "Acceleration and Passing Ability - A Comparison of Acceleration and Passing Ability for 1976 Passenger Cars and Motorcycles." Consumer Aid Series. U.S. Department of Transportation, National Highway Traffic Safety Administration.

This document is an annual publication containing data compiled by the NHTSA from information provided by the individual motor vehicle manufacturers in response to Department of Transportation regulations. Acceleration and passing ability of foreign and domestic automobiles and motorcycles are tabulated. Performance is ranked by seconds of elapsed time in descending order from best to worst with the total range of performance for all makes/models shown on each page for comparison. Data apply to new vehicles, after suitable break-in and adjustment according to the regulations. The data were used in this study to evaluate vehicle performance with respect to passing capability within the suggested criteria. (See also, References 32 and 33)

21. A Policy on Geometric Design of Rural Highways. American Association of State Highway Officials, 1965.

The AASHTO "Blue Book" forms the nationally accepted policy and guidelines for design of rural highways. The sections applying to passing sight distance were critically evaluated with respect to satisfaction of safety needs for current vehicle and driver characteristics.

22. "Official Rulings on Requests for Interpretations, Changes, and Experimentations," Manual on Uniform Traffic Control Devices for Streets and Highways. Volume VII, September 1976, pp. 23-24.

In this revision, Section 2C-39, NO PASSING ZONE sign (W14-3) was changed to read: "Because of the demonstrated target value given by this sign in critical passing maneuvers, the NO PASSING ZONE sign should be used on two-lane roads to warn of the beginning of the no-passing zones identified by either conventional pavement markings or DO NOT PASS signs or both. When used, it shall be erected on the left side of the roadway at the beginning of the no passing zones."

23. Normann, O. K. "Driver Passing Practices," HRB Bulletin 195, 1958.

Normann observed 476 passing maneuvers in 1957 on three of the sites where the 1938 studies (see reference 10) had been conducted. He found that speeds of both passing and passed vehicles were higher in 1957 [passed vehicles about 3 to 4 mph (4.8 to 6.4 km/h) faster than in 1938; passing vehicles about 6 to 7 mph (9.7 km/h to 11.3 km/h) faster]. Although the speed differential between passing and passed vehicles had increased from 10 mph (16.1 km/h) to 13 mph (20.9 km/h), the left lane occupancy time decreased by about 0.5 seconds. The left lane occupancy distance increased by about 100 ft (30.5 m) in 1957. Normann concluded that there was little evidence to indicate that 1957 practices of marking no-passing zones should be changed due to changes that had occurred in vehicle design and driver performance.

24. "Large Cars," Consumer Reports. Consumers Union of United States, Inc. Mount Vernon, New York. Vol. 42, No. 2, p. 87, February 1977.

25. "Compact Wagons," Consumer Reports. Consumers Union of United States, Inc. Mount Vernon, New York. Vol. 41, No. 7, p. 389, July 1976.

26. "Four Subcompacts," Consumer Reports. Consumers Union of United States, Inc. Mount Vernon, New York. Vol. 42, No. 6, p. 341, June 1977.

27. "Three Vans," Consumer Reports. Consumers Union of United States, Inc. Mount Vernon, New York. Vol. 42, No. 9, p. 527, September 1977.

28. "Two Wagons," Consumer Reports. Consumers Union of United States, Inc. Mount Vernon, New York. Vol. 42, No. 4, p. 210, April 1977.

The above publications contain acceleration characteristics of various makes and models of automobiles. Data include acceleration times to accelerate from 0 to 30 mph (0 to 48.3 km/h), 0 to 60 mph (0 to 96.6 km/h), and from 45 to 65 mph (72.4 to 104.6 km/h). The data were used to determine the range of accelerations during the pass initiation phase of the maneuver.

29. Performance Data for New 1971 Passenger Cars and Motorcycles. Consumer Information Series, U.S. Department of Transportation, National Highway Safety Bureau. Vol. 2, No. 1, October 1970.

30. Performance Data - New 1972 Passenger Cars and Motorcycles. Consumer Information Series. U.S. Department of Transportation, National Highway Safety Administration. Vol. 3, No. 1, November 1971.

31. Performance Data - New 1973 Passenger Cars and Motorcycles. Consumer Information Series. U.S. Department of Transportation, National Highway Traffic Safety Administration. Vol. 4, November 1972.

32. Acceleration and Passing Ability - A Comparison of Acceleration and Passing Ability for 1974 Passenger Cars and Motorcycles. Consumer Aid Series. U.S. Department of Transportation, National Highway Traffic Safety Administration. Vol. 1, Part 3, November 1973.

33. Acceleration and Passing Ability - A Comparison of Acceleration and Passing Ability for 1975 Passenger Cars and Motorcycles. Consumer Aid Series. U.S. Department of Transportation, National Highway Traffic Safety Administration. Vol. 5, Part 3, January 1975.

34. Consumer Information Brochures of 1977 Model Vehicles, Published by Vehicle Manufacturers.

    The data from the above referenced sources were used to determine the range of distances for low-speed and high-speed passing maneuvers, which in turn was used to determine a suggested minimum length of "passing zone." The data revealed that passing distances are increasing yearly and that at least 500 ft (152 m) are needed to allow all types of automobiles on the roads to pass a 20-mph (32.2 km/h) truck -- not including the initiation and return maneuver.

35. Cunagin, W., Abrahamson, A., Alemar, P., and Mao, A. "Driver Eye Height Laboratory Report," Graduate Civil Engineering Course, Texas A&M University, April 1978 (unpublished).

    This unpublished report was prepared by the four graduate students in partial fulfillment of the requirements of a graduate course in transportation engineering. The results of the photographic measurements of driver eye height further substantiated that a 3.5 ft (1.07 m) driver eye height is more representative of current driver/vehicle characteristics than the 3.75 ft-height (1.14 m) currently being used for marking purposes. (See also, Reference 16).

36. McDonald, Larry B., "A Model For Predicting Driver Work Load In the Freeway Environment: A Feasibility Study," A Dissertation, Texas A&M University, College Station, Texas, August 1973 (unpublished).

McDonald's work was used to determine a basis on which to estimate driver workload during the passing maneuver so that traffic control devices could be evaluated with respect to positional need and probability of being detected under the driver task at the necessary point in the maneuver. McDonald's 1-activity-per-2 seconds representing that workload requiring full concentration was used as a basis to rank the workload during the elements of the maneuver.

37. Kearney, Edward F. and Joanne Chusid. "State Laws on No-Passing Zones." National Committee on Uniform Traffic Laws and Ordinances. U.S. DOT, FHWA Requisition No. 41-41-7137, 1977 (unpublished).

The Kearney/Chusid report contains State-by-State detailed comparison of no-passing zones laws to the terminology in the Uniform Vehicle Code and Model Traffic Ordinance. The report was referenced, with presentation of summarizing observations, to illustrate that many of the engineering questions regarding safe passing criteria are also of concern to the legal profession. The concepts developed in this research study are directly responsive to several of the problem areas identified by Kearney and Chusid.

38. National Committee on Uniform Traffic Laws and Ordinances. "Uniform Vehicle Code and Model Traffic Ordinance," 1968.

The UVC/MTO represents the standard for State motor vehicle and traffic laws. Since the proposed concept of advance marking no-passing zones is innovative, the UVC/MTO sections pertaining to passing operations required review to determine if modifications would be necessary. Mr. Kearney, Executive Director of the National Committee on Uniform Traffic Laws and Ordinances, has indicated that no changes would be necessary to accommodate the proposed advance marking treatment.

39. Hruska, Stanley J. "Studies of Methods and Materials for Delineating Channelization," Civil Engineering Department, Texas A&M University, College Station, Texas, August 1963 (unpublished).

This study contains detailed visibility distances for various types of channelizing materials and geometric shapes. Data are reported for both day and night conditions. The data were used to establish the expected visibility distance for pavement markings for both daytime and nighttime conditions.

40. Correspondence, U.S. Memorandum. U.S. DOT, BPR, Office of Traffic Operations (no date stated) Subject: "Minimum passing sight distance for design and marking no-passing zones."

The rationale on which the MUTCD no-passing zone sight distance values are predicated could not be determined. In response to the question at the workshop on enforcement (see Reference 19), the quoted explanation was offered. The origin of the correspondence is unknown; however, it is presented because it represents the only available source of information regarding the subject.

41. Engineering News Record, March 28, 1978.

42. Wall Street Journal, April 4, 1978, p. 28.

43. Ledbetter, W. B., et al., "Techniques for Rehabilitating Pavements Without Overlays - A Systems Analysis," Vol. 2 Appendices, FHWA Report No. FHWA-RD-77-132.

These three sources were used to obtain historical trend data on the relative increase in construction costs. These were used to extrapolate 1974 cost data to an approximate 1978 equivalent cost.

44. Byington, S.R. "Economic and Location Criteria for a Passing-Aid System," Unpublished Report, Federal Highway Administration, May 1967.

Byington investigated the economic feasibility of the Passing-Aid System using computer modeling. Extensive data are presented on the length and frequency of sight restrictions on two-lane highways. These data were used to estimate the number of no-passing zones on the two-lane highway system of the United States.

45. Highway Statistics, 1974. U.S. Department of Transportation, Federal Highway Administration, U.S. Government Printing Office, Table SM-110, p. 223.

46. "Highway Capacity Manual - 1965," Highway Research Board Special Report 87, 1965.

These two basic sources provided highway system characteristics which permitted an estimate of the number of passing maneuvers on the two-lane highway system made each year.

47. "Study of No Passing Zone Signing," Conducted by Michigan State Highway Department, May 1965.

The Michigan State Highway Department conducted a before and after study of the effectiveness of the no-passing pennant sign. Statistically significant better visibility distances of the left sign mounting were found when compared to the right side regulatory sign. Changes in driver behavior, specifically percentage clipping the no-passing barrier stripe, and accident experience were reported. These data were used to estimate the percentage of the passing drivers that could benefit from the proposed advance treatment system.

48. "Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems," U.S. Department of Transportation, Federal Highway Administration, 1974.

49. Accident Facts - 1974, Statistics Division, National Safety Council, Chicago, Illinois, 1974.

Data from these two sources were combined in order to estimate the distribution of passing related accidents among the three basic accident types (i.e. PDO, Injury and Fatality).

50. "Identification and Evaluation of Remedial Aid Systems for Passing Manuevers on Two-Lane Rural Roads," Vol. II, Research Report of the Franklin Institute Research Laboratories, Federal Highway Administration Technical Report 1-201, February 1970.

A detailed analysis of the parameters of the passing maneuver on two-lane highways is presented. One finding of this report was most significant -- about 10 percent of the accidents on the two-lane highway system nationally were passing-related. Combined with the estimate obtained from references 48 and 49, an estimate of the passing related accidents was possible.

51. Kemper, W., P. Huntington, and S. Byington, "Overtaking and Passing Vehicle Accidents," Public Roads Magazine, Vol. 37, No. 3, December 1972.

An outstanding report on the characteristics of overtaking and passing accidents on two-lane highways, this publication provided a basic estimate of the percentage of passing related accidents which could be expected to result in occupant injury. These data were used to estimate the number of injury and PDO accidents potentially eliminated by the advance treatment of no-passing zones.

52. Faigin, Barbara Moyer, "1975 Societal Costs of Motor Vehicle Accidents, National Highway Traffic Safety Administration, Washington, D.C., December 1976.

    The NHTSA cost values for fatal, injury, and property-damage-only accidents represent the most widely accepted values for cost analyses. The cost values from this document were used to estimate the annual dollar savings by use of the proposed advance treatment by converting the estimated reduction in the number of the three accident types to dollar amounts.

53. "Problems Associated with Proposed Passing, No-Passing, and Restrictive Passing Zones on Highways." Workshop held by Highway User's Federation for Safety and Mobility, Washington, D.C., January 1978. Rankin, Woodrow, W., Sonsteby, Ornulv, moderators.

    The project interim report containing proposed criteria, advance treatment and warrants for passing/no-passing zones was reviewed by thirty-six traffic engineers from throughout the country. A two-day workshop was held, following this review, to discuss the research findings and the proposed concepts. Attendees included members of the National Advisory Committee on Traffic Control Devices, FHWA research personnel, and members of the research staff. The specific request resulting from the workshop was that an economic anlaysis be made to evaluate the benefits that could be expected from implementation of the proposed treatments. Also, it was the consensus that the concepts should be field-tried on two-lane highways. The economic analysis presented in the report was conducted in response to the workshop attendees' expression of need.

54. "Highway Capacity Manual - 1950." U.S. Government Printing Office, 1950.

    This source presents basic relationships between total passes per mile per hour and various levels of average daily traffic (see p. 42). These data were used to estimate the total passing maneuvers for various ADT levels. The sum of these estimates became the total estimated daily passing maneuvers on the two-lane highway system.

55. Snedcor, George W. "Statistical Methods" Iowa State College Press 1956.

    A basic text on applied statistics, this source was used to establish the acceptable level of R^2 for regression models in order to be able to use them for predictive purposes. Snedcor suggests a minimum R^2 of 0.80.

56. Box, Paul C. and Associates. "Driveways," Chapter 5 Traffic Control and Roadway Elements - Their Relationship to Highway Safety. Highway Users Federation for Safety and Mobility, 1970, p. 2.

A part of an extensive series of reports on highway safety, this document contains valuable information regarding expected accident rates for given geometric situations. In this research the expected accident rate for two-lane urban streets was obtained and used to statistically evaluate the accident experience on two-lane urban streets marked with a single solid yellow centerline.

57. Meyer, M. B. "1970 MUTCD vs. The Single Solid Yellow Centerline," A paper presented to the District IV ITE Conference, Kansas City, Missouri, June 22, 1972. (Also a report of the Traffic Engineering Department, City of Cedar Rapids, Iowa)

Mr. Meyer, Director of Transportation, Cedar Rapids, Iowa, presented challenging questions regarding the need for the single solid yellow centerline in urban areas. The questions are presented in this report to present the traffic engineer's viewpoint of the need that was expressed for such a marking system when the 1971 MUTCD did not permit use of the single solid centerline. Experience around the nation has generally indicated that the anticipated problems failed to materialize; thus, the need for such a marking does not appear to be particularly acute.

58. Walton, N. E., J. M. Mounce, and W. R. Stocktor. "Signs and Markings for Low Volume Rural Roads." Final Report, FHWA Contract DOT-FH-11-8249, Texas Transportation Institute, September 1975.

Walton, et al. questioned 270 drivers to evaluate driver understanding of markings and signs. The study findings indicated that, double solid centerlines, even when very narrow, were viewed by almost 69 percent of subject drivers to denote "passing prohibition." A large majority of respondents indicated that the "double-narrow" line did not differ in meaning from the normal double line. The same did not hold true for the single solid yellow line. The meaning was apparently confusing as evidenced by about 42 percent interpreting it as "prohibitive" and about 31 percent interpreting it as "permissive." The driver interpretation studies further enforced the rather widespread misunderstanding that was evidenced in the human factors laboratory studies in this research.

59. Parker, Martin R., Jr., and Mark E. Rawlings. "Evaluation of Centerline Pavement Marking Patterns on Two-Lane Highways in Mountainous Areas -- Working Plan," Virginia Highway and Transportation Research Council, Charlottesville, Virginia VHTRC-78-WP10. December 1977.

The purpose of this study is to determine if the single broken yellow centerline pattern used on two-lane highways in mountainous areas should be replaced with the standard MUTCD marking patterns or some other marking system. The emphasis of the research will be a comparison of the effects of the mountain and standard markings on operational and safety aspects of travel such as vehicle speeds, volumes and passing maneuvers. The study will produce recommendations that can be used by the Department's administrators to determine the appropriate marking pattern for mountainous highways. The specific objectives of the study are to --

1. determine if significant differences exist between observed operational and safety characteristics for the mountain marking pattern and the standard marking pattern;
2. examine public interpretation of the road marking and signing systems;
3. determine the safe and acceptable passing distances for roadways with operating speeds less than 50 miles per hour; and,
4. outline the legal implications of using a non-MUTCD roadway and signing system.

The scope of the study will include a literature review, a questionnaire survey of marking practices in other States, and data surveys. The study is scheduled to be completed by October 1978.

60. Huber, Anton, Donald R. Hatcher, and Graeme D. Weaver. "Passing and No-Passing Zones: Signs, Markings, and Warrants--Accident Analysis" (TTI Report RF 3453-2) September 1978 (unpublished).

This report is a support document presenting the methodology, results, and conclusions of an analysis of passing-related accidents that occurred on 2-lane rural roadways in California, Kentucky, and Texas. The passing accident data were extracted from the 1973 and 1975 accident files from California and Texas and from the 1973 Kentucky files. To identify the elements of passing accidents that can be considered "causative factors," analyses of variables including traffic, environmental conditions, geometric conditions and traffic control devices were conducted on the data from each State. The results of these analyses have been incorporated into the final research report.

61. Richards, Stephen H., Graeme D. Weaver, R. Dale Huchingson, and Donald L. Woods. "Passing and No-Passing Zones: Signs, Markings, and Warrants -- Human Factors Laboratory Studies" (TTI Report RF 3453-3) September 1978 (unpublished).

An integral part of the research involved determination of passing practice and problems associated with current marking practice and driver understanding of candidate traffic control devices to improve the safety aspects of marking no-passing zones. Human factors laboratory studies were conducted to evaluate these factors.

Human factors studies were also conducted to evaluate expected driver understanding of the single solid yellow centerline for use in designating "restrictive" passing zones on two-lane highways.

This report is a support document containing a description of the human factors studies conducted, evaluation of the study findings, and tabulated responses to the questions answered by subject drivers to document the data which influenced the proposed criteria, warrants, and traffic control devices developed and presented in the final report. The results have been incorporated into the final research report.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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